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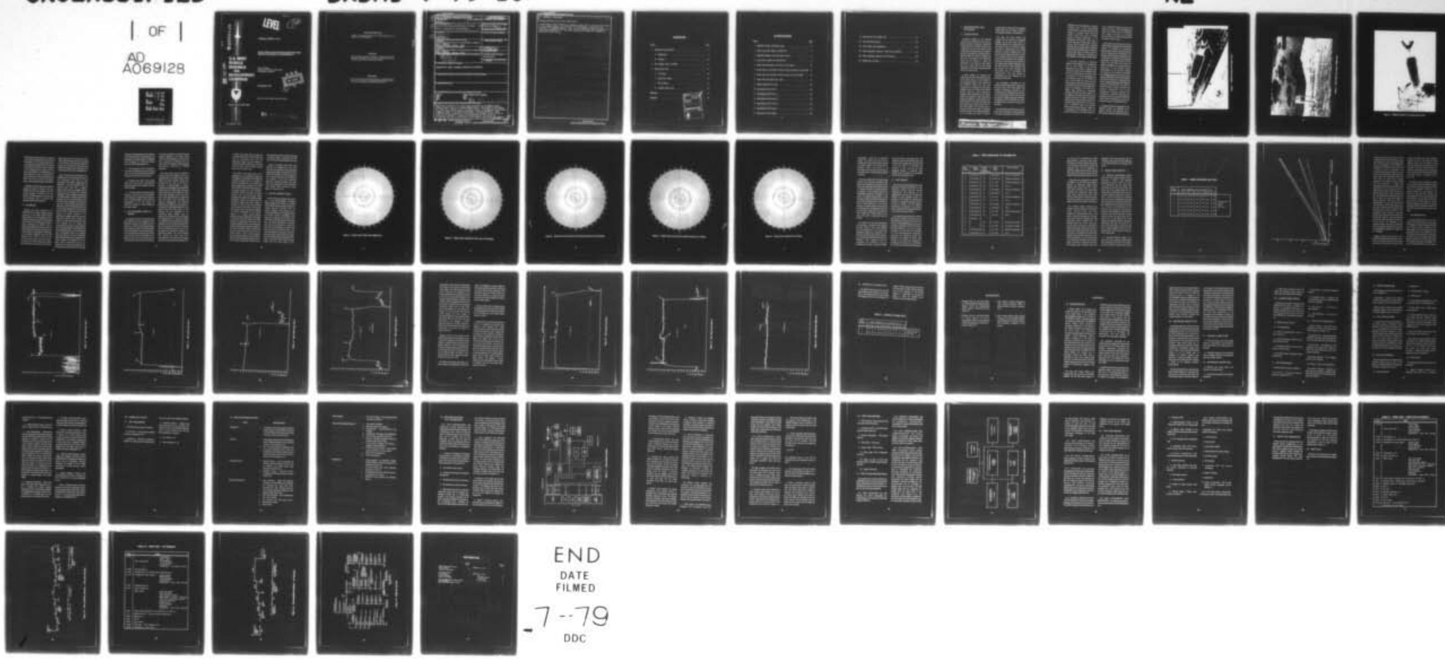

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TECHNICAL REPORT T-79-10

STATIC FIRING TESTS FOR EVALUATION OF PLUME EFFECTS ON MISSILE RF SUSCEPTIBILITY.

Lee R. Johnson
Guidance and Control Directorate
Technology Laboratory

20 September 1978

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U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Redstone Arsenal, Alabama 35809

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Theoretical analysis of the electrical properties of the REDEYE missile exhaust plume attributes a maxmum conductivity to the plume of a few tenths of a mho/m in a region close to the motor nozzle. The conductivity decreases along the length of the plume and exhibits a radical dependence. When a REDEYE missile is exposed to an RF field, the presence of the current on plume can be expected to affect the distribution of the current on the missile skin and to thus affect the RF energy coupled into the interior

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20. ABSTRACT (Continued)

through apertures such as the seeker dome.

A plume Effects Test Program was conducted in May 1977 to evaluate the effect of the missile plume on the coupling of electromagnetic energy into the interior of the REDEYE missile. The test were conducted with the missile in a strap-down configuration at the White Sands Missile Range Electromagnetic Radiation Effects site.

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1. BACKGROUND AND SUMMARY

A. BACKGROUND

Theoretical analysis of the electrical properties of the REDEYE missile exhaust plume attributes a maximum conductivity to the plume of a few tenths of an mho/m in a region close to the motor nozzle [1]. The conductivity decreases along the length of the plume and exhibits a radial dependence. When a REDEYE missile is exposed to an RF field, the presence of the conductive plume can be expected to affect the distribution of the current on the missile skin and to thus affect the RF energy coupled into the interior through apertures such as the seeker dome.

A Plume Effects Test Program was conducted in May 1977 to evaluate the effect of the missile plume on the coupling of electromagnetic energy into the interior of the REDEYE missile. The tests were conducted with the missile in a strap-down configuration at the White Sands Missile Range (WSMR) Electromagnetic Radiation Effects (EMRE) site. The captive missile was exposed to an RF field and the interference signals at various points in the missile circuitry were monitored before and after sustainer motor firing. The objective of the Plume Effects Test Program was to determine whether the plume is significant in terms of effect on the coupled energy and, if so, to evaluate the extent to which an artificial plume, constructed from graphite loaded foam by the Georgia Institute of Technology, simulates a real plume [2].

The May 1977 Plume Effects Test Program was not carried out as originally planned. On the first static firing of a REDEYE missile at the EMRE test site, it was observed that an interference signal, measured at a selected point in the missile electronic circuitry, changed level at the instant of motor ignition and did not return to the original level after motor burnout. This was an unexpected result. Changes in interference levels caused by the presence of the exhaust plume should disappear when the motor burns out. The remainder of the test period was spent devising and conducting tests to investigate this phenomenon. The step change in interference level was observed on all subsequent firing tests.

The mechanism responsible for the interference level change was not discovered during the May 1977 Plume Effects Test Program. Subsequently, laboratory tests were conducted at the Dahlgren Laboratory of the Naval Surface Weapons Center and a second static firing test series was conducted in September 1977 at the EMRE site. These investigations did not disclose the cause of the effect.

The step change in interference level at the instant of motor ignition caused questions to be raised concerning the validity of the

REDEYE test data acquired in anechoic chamber tests. If the susceptibility characteristics of a tactical missile actually change in a stepwise manner when the sustainer motor fires, then an in-flight missile responds differently to an interference environment than does a missile which has not been fired. If such is the case, and if missiles used in anechoic chamber tests are representative of prefired rather than fired missiles, then the anechoic chamber data either is invalid or must be appropriately modified for predicting the susceptibility of an in-flight tactical missile.

It was thus important to determine whether the interference level change was due to some change in the intrinsic properties of the motor or guidance and control unit (GCU) of the missile and would occur in a tactical missile, or whether it was a consequence of the test configuration or instrumentation used for the EMRE site tests. At the EMRE site, firing tests had been conducted with the missile mounted in a strap-down fixture atop a fiberglass pole. Power was supplied to the missile by a battery pack enclosed in a cylindrical container which fit around the missile. An RF telemetry transmitter was fitted into the warhead section of the missile to telemeter missile data to a ground receiver located in a building several hundred feet from the test area. A REDEYE missile with attached battery pack is shown in *Figure 1*. *Figure 2* is a photograph of the fiberglass pole with strap-down fixture at the top and *Figure 3* shows a REDEYE missile mounted in the strap-down fixture. This test configuration allows the possibility that the interference level change was due to an on-board telemetry effect or an effect associated with the strap-on battery pack.

A test program was initiated by the Army SEMI Program Manager with the primary objective of resolving the uncertainties concerning the validity of anechoic chamber data for predicting the susceptibility of an in-flight missile. Secondary objectives were to determine the details of the mechanism responsible for the interference level shift, measure the real effect of the plume on missile susceptibility, and acquire data for evaluation of the artificial plume. Responsibility for the technical planning and direction of the program was assigned to the Missile Electronic Counter-Countermeasure (MECCM) Center of the Guidance and Control Directorate, Technology Laboratory, Missile Research and Development Command (MIRADCOM). The office of Missile Electronic Warfare (OMEW) was assigned responsibility for overall management, direction, planning, and coordination to implement the program. A management plan was prepared by OMEW which created a management structure and designated program responsibilities [3].

A detailed test plan was prepared by the MECCM Center and published on 3 January 1978 [4]. The approach was to first conduct missile RF response tests at the

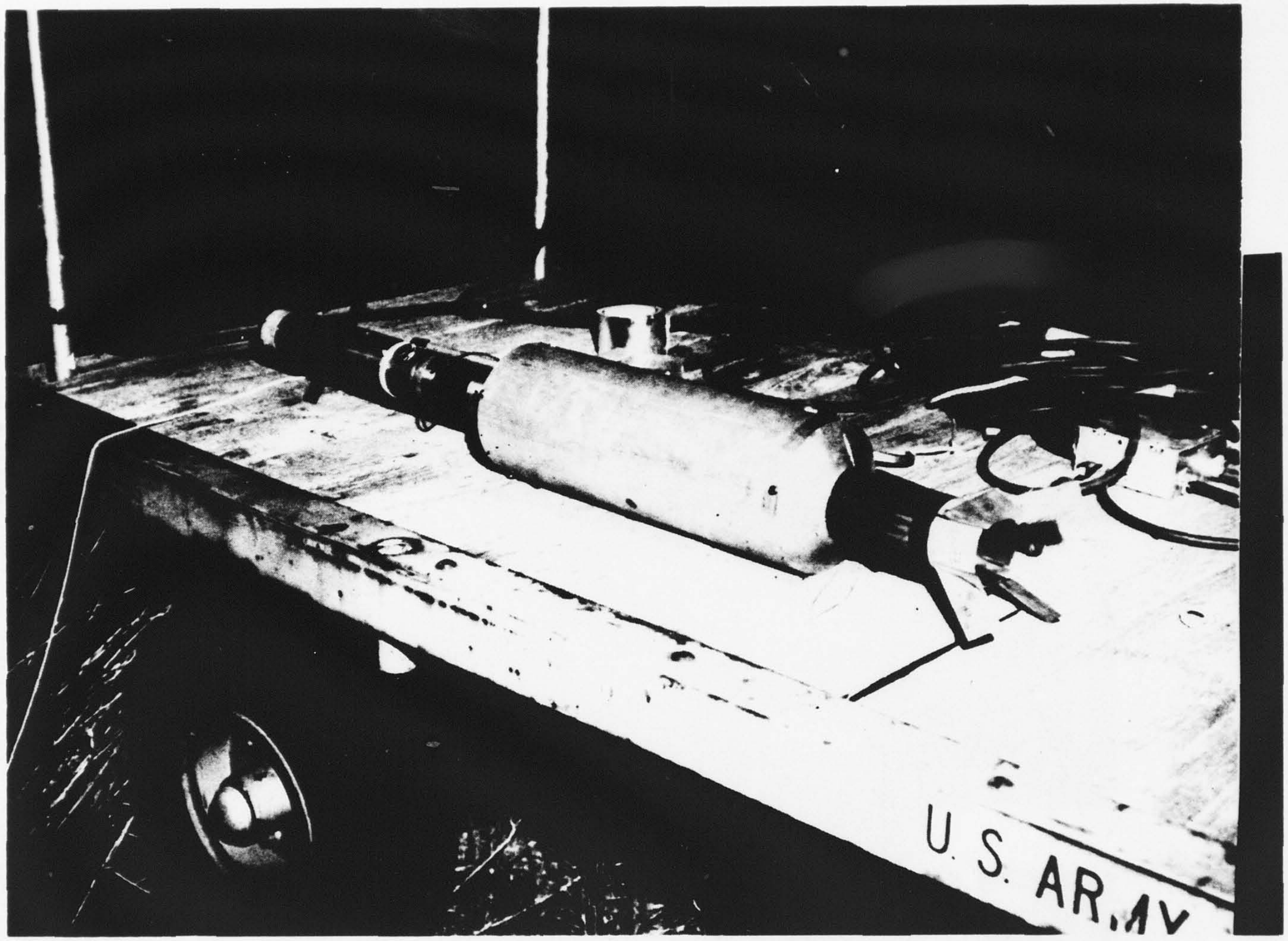

Figure 1. REDEYE missile with battery pack.

Figure 2. Static firing test range at EMRE site.

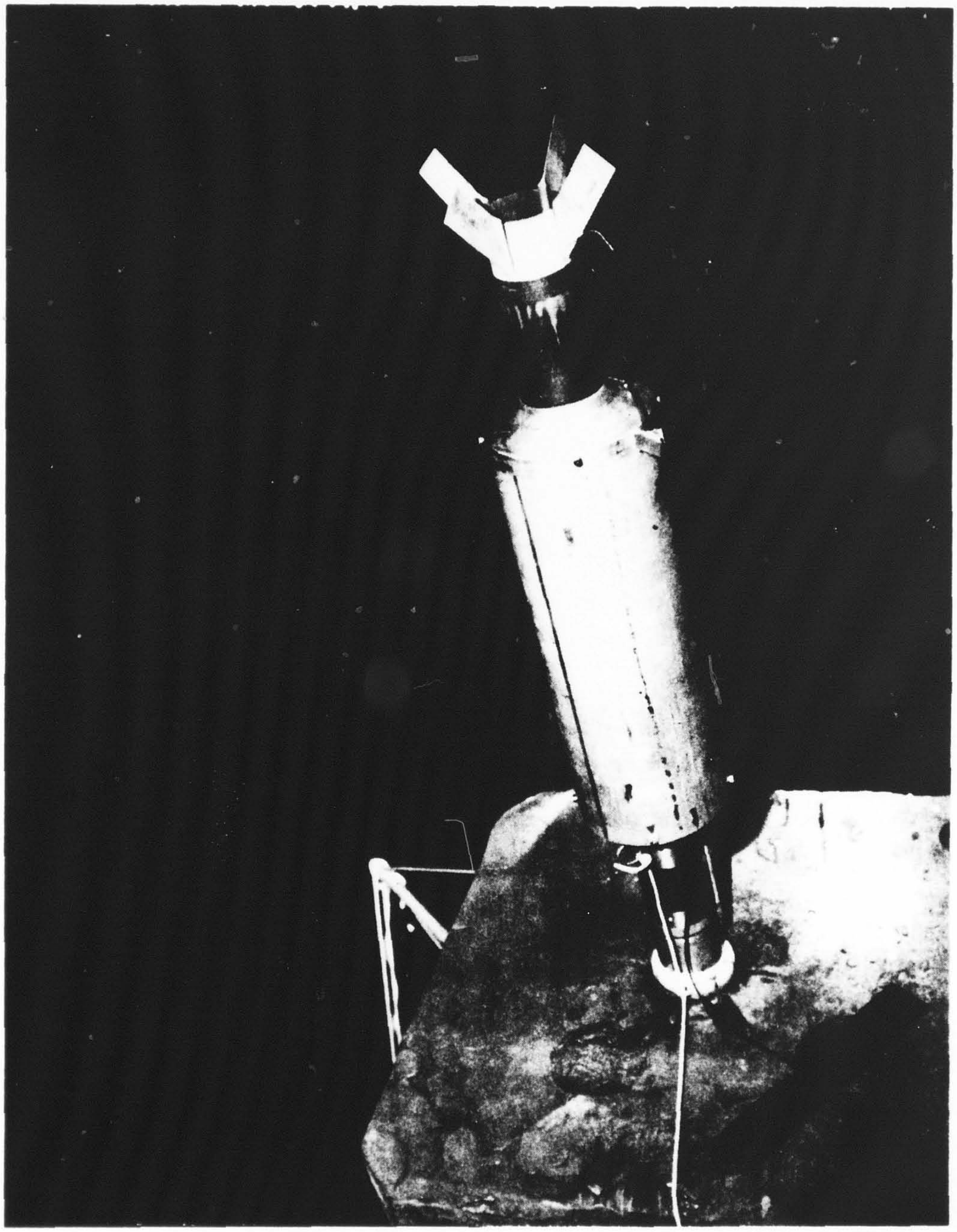

Figure 3. REDEYE missile in the strap-down fixture.

OMEW RF chamber and then to perform tests with both expended and live motors at the EMRE site. The principal objective in conducting the chamber tests was to acquire a data base for each GCU and for a number of the expended motors which would be used at the EMRE site. The EMRE site test plan employed a process of elimination to isolate the source of the interference level shift to the GCU, the motor, the battery pack, or the on-board telemetry transmitter.

Chamber tests were conducted at OMEW during the month of January 1978 and EMRE site tests were conducted from 26 January through 2 February 1978. The purpose of this document is to describe the tests performed and to document the program results and conclusions.

B. SUMMARY

Chamber tests were conducted at the OMEW facility and static firing tests were conducted at the White Sands Missile Range EMRE site. The chamber tests were performed to acquire a missile response data base, to check out the fiber optics telemetry system developed by OMEW, and to investigate possible causes of the anomalous missile response observed during previous static firing tests. Investigations conducted in the chamber indicated that the squib shorting wires, which in most of the previous static firing tests had extended a few inches out the rear of the missile, might be responsible for the change in interference signal level observed at the time of motor firing. Missile response patterns were made in the chamber both with and without the squib wires extending out of the missile and significant changes in missile response were observed between the two configurations.

Static firing tests were conducted at the EMRE site to first determine the cause of the interference level shift at squib detonation. The missile configuration was identical to the configuration used for previous static firing tests. A strap-on battery pack was used to power both the missile and an on-board RF telemetry transmitter. With the missile on the stand at a 30 degree angle of incidence, the RF field strength was set at several different levels and the interference signal was measured at each level. This procedure was carried out with the squib wires extending from the rear of the missile, pushed back into the missile and cut off short inside the skirt. The data showed the missile response to be significantly changed when the wires were allowed to extend from the missile. Two firings were then conducted with the squib wires extended and two firings were conducted with the wires cut short inside the skirt. Permanent shifts in interference level were observed when the wires were extended and no permanent shifts were observed when the wires were cut short. Following these tests firing tests were conducted at incidence angles of 90 degrees and 135 degrees, with the squib wires cut short, to acquire data on the effect of the plume. The artificial plume constructed by the Georgia

Institute of Technology was then mounted on the missile and the missile response was measured at incidence angles of 30 degrees and 135 degrees. The conclusions derived from the static firing program are:

- The permanent shift in interference level observed during previous static firing tests was caused by the squib wires suddenly ceasing to be connected to the missile.

- Chamber data taken with dummy motors (no squib wires) is valid since the squib shorting wires are missing on a tactical missile in flight.

- True plume effects are small at the RF frequency used for the tests and probably can be ignored, although final conclusions await a detailed analysis of the data and extrapolation of the test results, by theoretical methods, to other frequencies and aspect angles.

2. RF CHAMBER TESTS AT OMEW

In compliance with the overall test plan, RF radiation tests were conducted on the REDEYE missile at the OMEW RF test facility at the White Sands Missile Range. The principal purpose in conducting these tests was originally to acquire a data base for each of the guidance and control units which would later be used at the EMRE site to determine the cause of the interference level shift observed on previous static firing tests at the time of sustainer motor firing. The test program specified in the Static Firing Program Plan(Appendix) was carried out and a sequence of additional tests was performed to investigate a missile response phenomenon observed by OMEW personnel.

The motor section used by OMEW to conduct some of the chamber tests was an expended motor in which sustainer motor squibs had been installed. Squib wires extended out the rear of the motor a distance of approximately 8 inches. Externally, this configuration resembled the missiles with live motors used in previous static firing tests at the EMRE site where squib wires extended out the rear of the motor until the squibs fired, at which time they were blown away. Internally, the electrical configuration was somewhat similar, but not identical, to a live motor. In the course of conducting chamber tests on a missile with this motor section, it was observed that the magnitude of the interference signal changed when the positions of the squib wires were changed. The magnitude of the interference signal was different when the squib wires extended straight out the rear of the missile than when the wires were bent around to lie along the missile. Tucking the wires into the rear of the missile also produced a change in the interference signal. This result indicated that possibly the squib wires were responsible for the interference level change that occurred during the static firing tests. If

a missile with squib wires out the rear responds differently to an RF field than one with no protruding wires, then the interference signal could be expected to change level during a firing test at the time when the motor squibs detonate and the squib wires are blown away.

The effect of the squib wires on the magnitude of the interference signal was investigated in the chamber by recording the interference signal level for a number of different configurations of the squib wires while maintaining a constant level of RF field strength. The missile was mounted on a rotatable pedestal in the chamber, illuminated with an RF field of constant intensity and the interference signal recorded as the missile was rotated through 360 degrees. *Figure 4* is a polar plot of the interference signal level versus angle of incidence of the RF field with the squib wires tucked into the rear of the missile. Zero degrees on the polar plot corresponds to nose-on illumination of the missile. *Figure 4* is a typical "missile antenna pattern" which shows the effect of the angle of incidence of the RF field on the missile response as measured by the level of the interference signal. *Figure 5* is the measured missile antenna pattern with all conditions the same as those for *Figure 4* except that the squib wires extend out the rear of the missile. *Figures 6* and *7* are the antenna patterns when the wires are out of the missile and bent forward along the bottom and top of the missile, respectively. *Figure 8* is the antenna pattern with all conditions the same as those for *Figure 7* except that the wires were shortened by approximately 2 inches.

Figures 4 through *8* show that in the chamber the configuration of the squib wires has a strong effect on the interference signal at some angles of incidence of the RF field. After this data was taken, the test plan for the static firing tests at the EMRE site was modified to add tests specifically planned to determine whether the squib wires were responsible for the interference level change which occurred at motor ignition on previous tests.

3. STATIC FIRING TESTS

A static firing test program was carried out at the Electromagnetic Radiation Effects (EMRE) test facility at the White Sands Missile Range during the period 27 January through 2 February 1978. The primary objective of this program was to resolve uncertainties concerning the validity of anechoic chamber susceptibility data, which were created by the interference level shift observed during previous static firing tests. To achieve this objective, a detailed test plan was formulated to isolate the source of the interference level shift to the GCU, the motor, the battery pack, or the on-board telemetry system [4]. If the level shift were found to be the result of a change in the intrinsic RF response properties of the motor or the GCU at the instant of motor firing, then the next stage of the

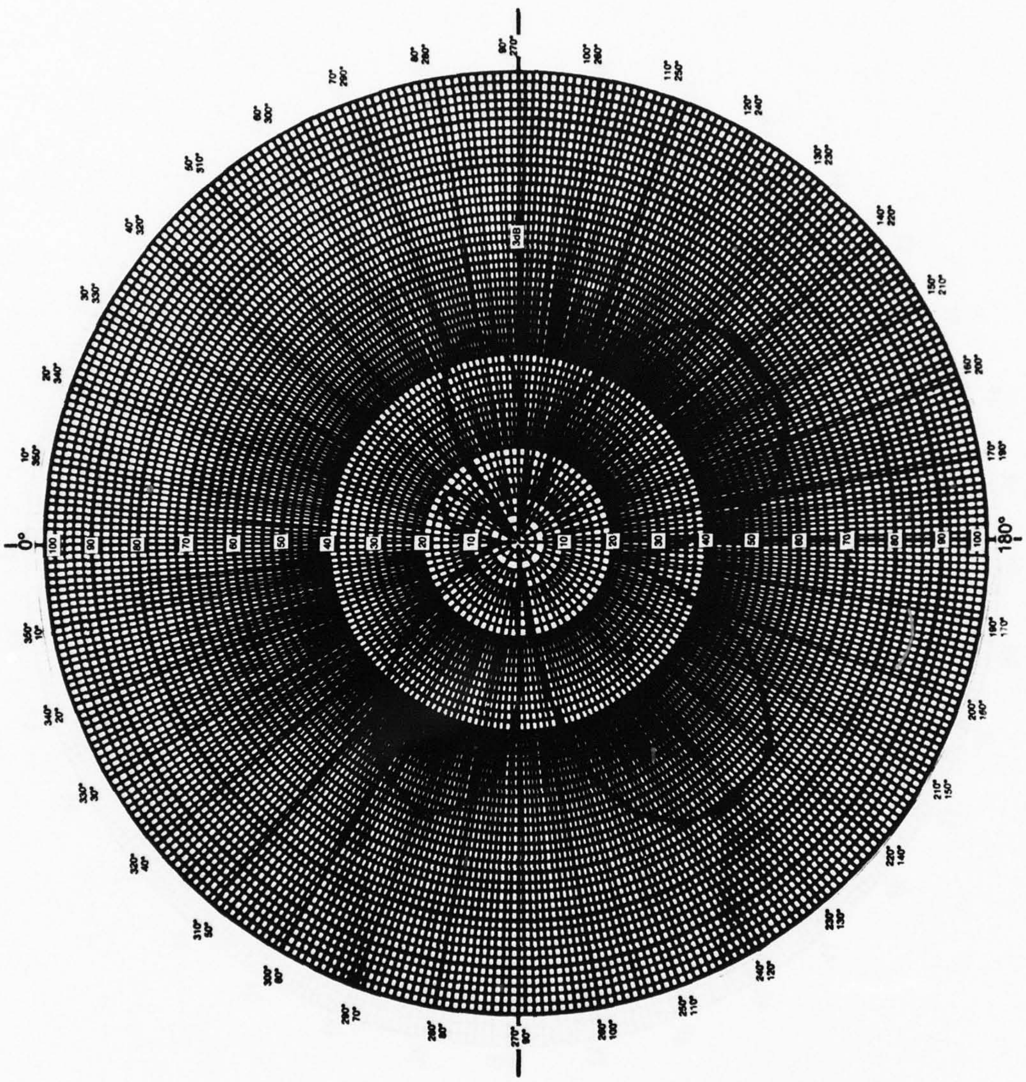

Figure 4. Squib wires tucked into missile skirt.

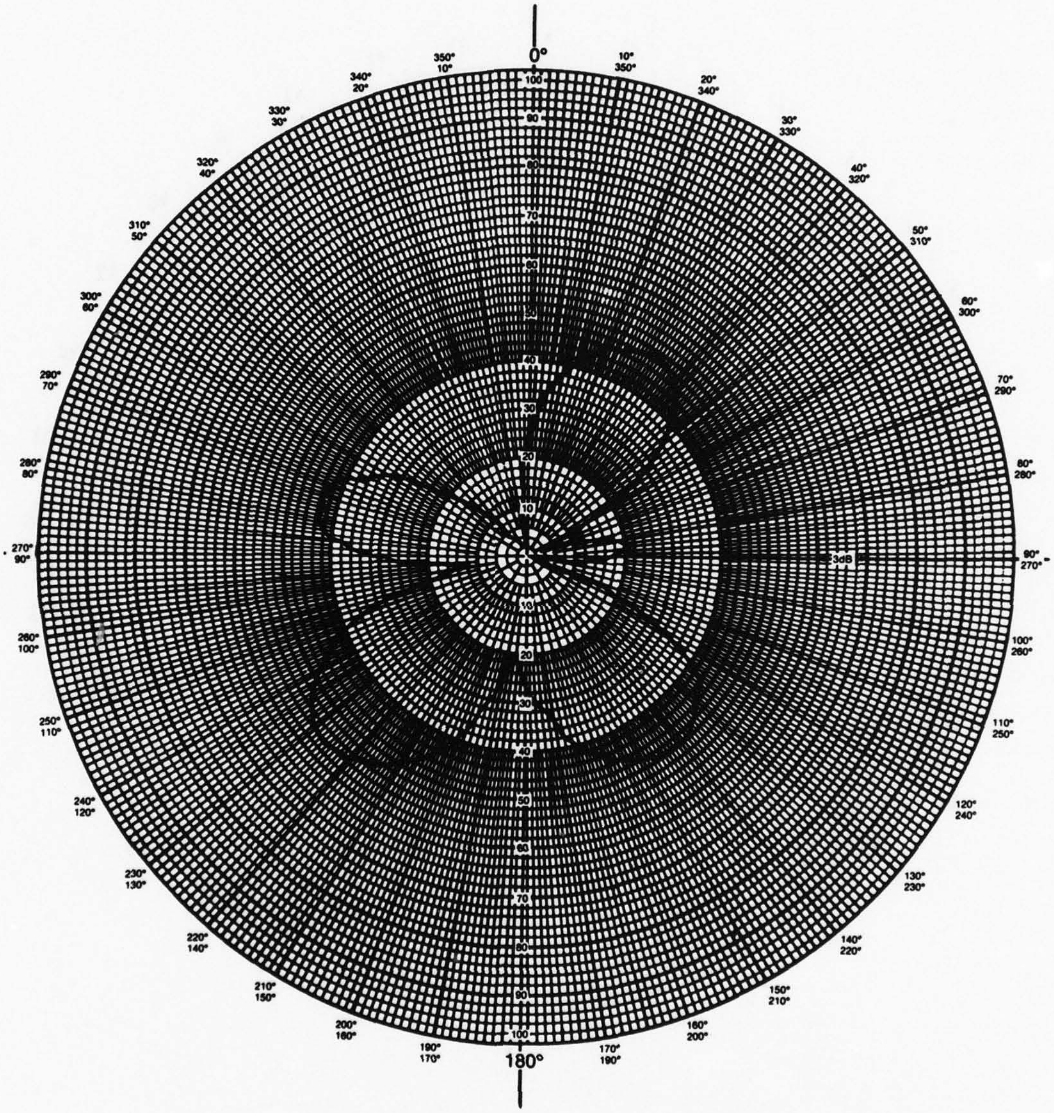

Figure 5. Squib wires extended out the rear of the missile.

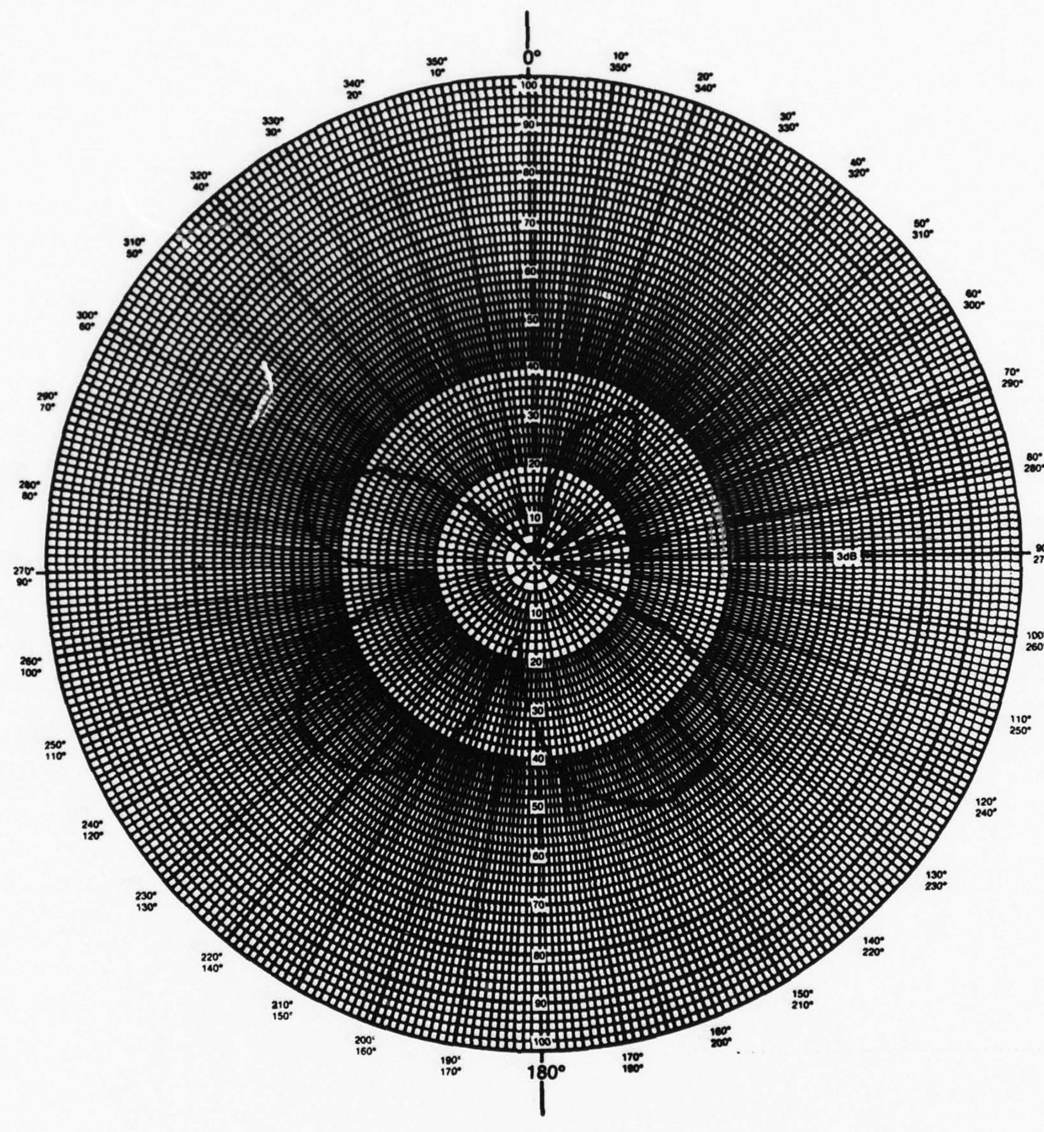

Figure 6. Squib wires out and bent forward along the bottom of the missile.

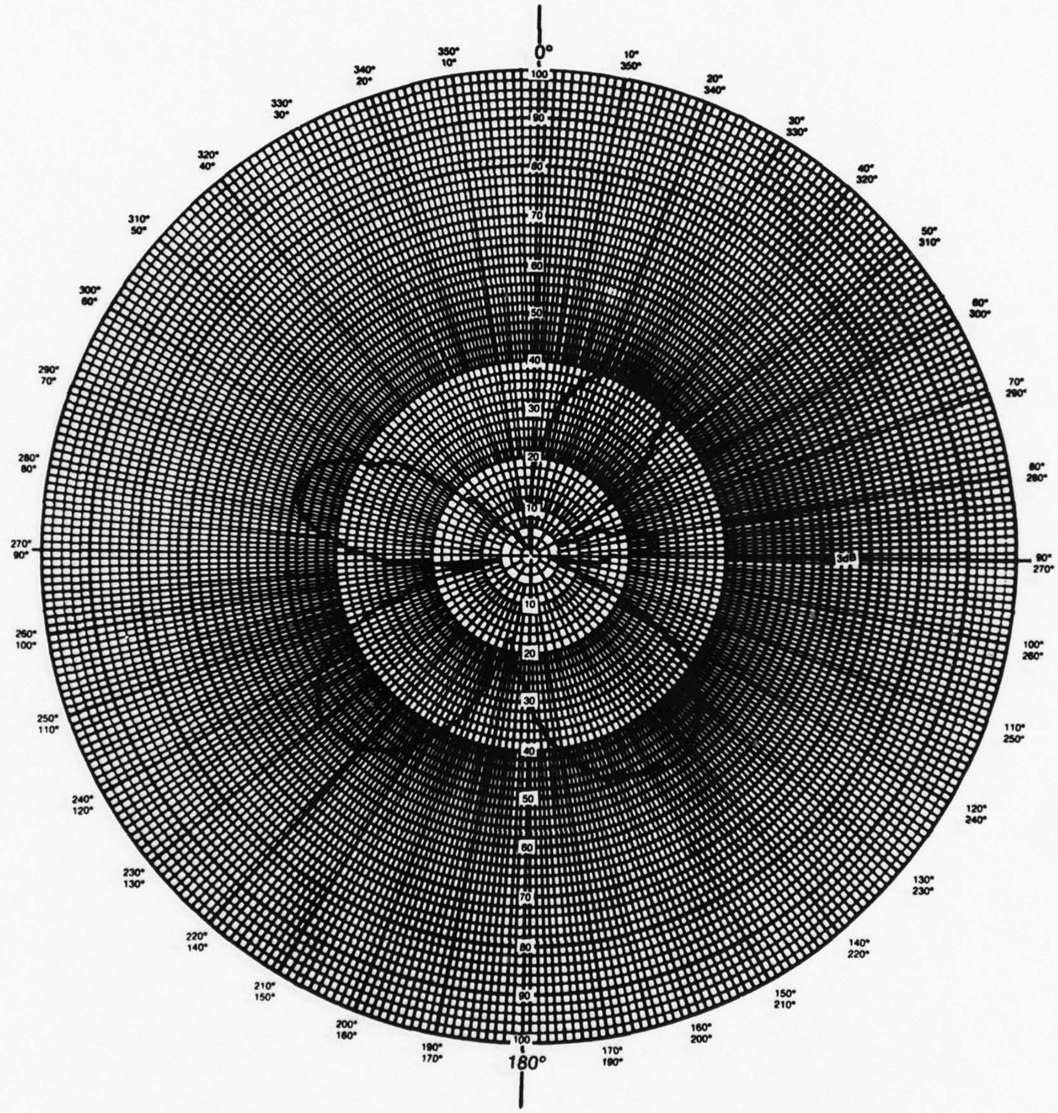

Figure 7. Squib wires out and bent forward along top of missile.

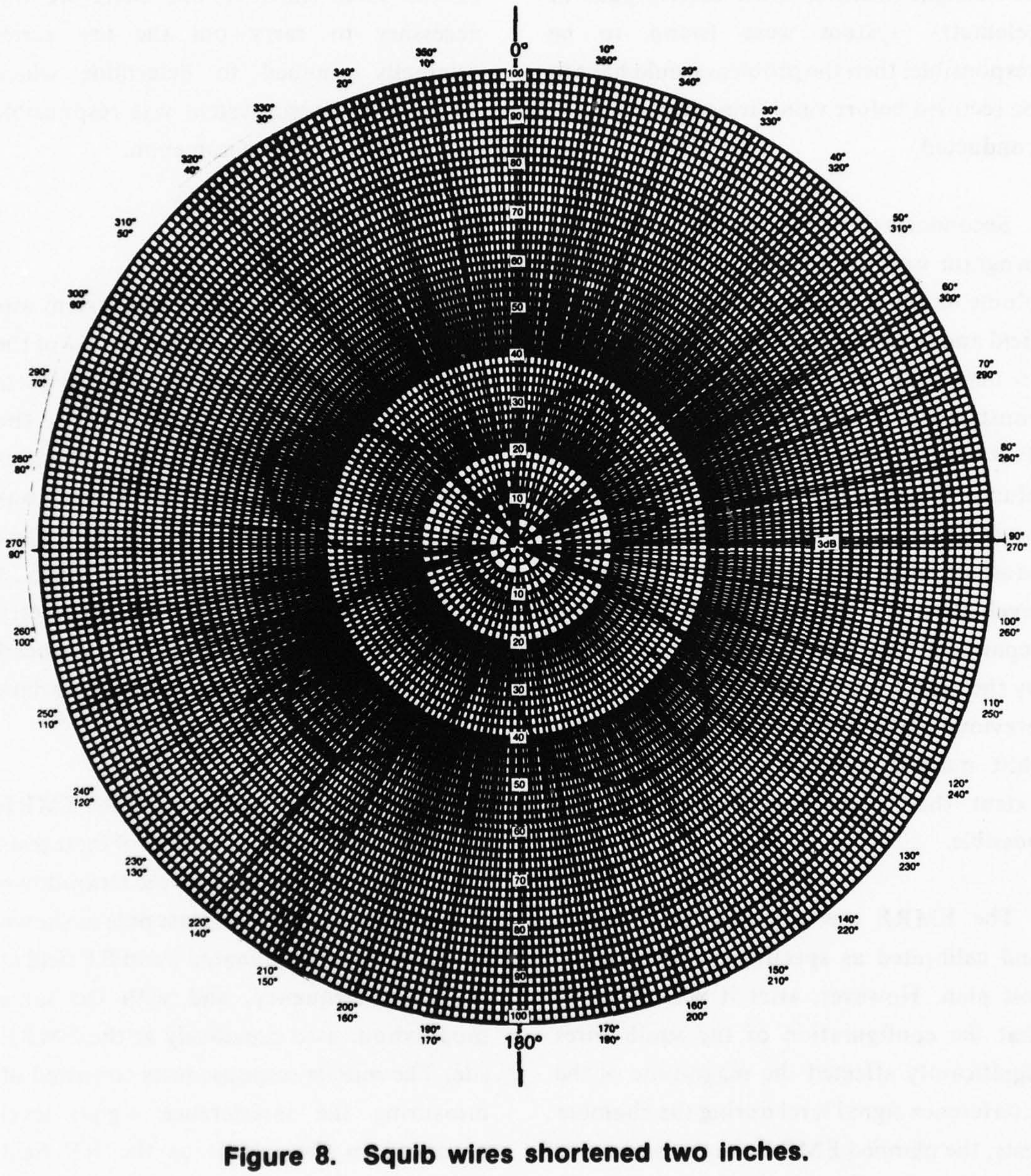

Figure 8. Squib wires shortened two inches.

investigation would be to determine whether the motors and GCU's used in chamber tests represented prefired missiles or in-flight missiles. If the battery pack or telemetry system were found to be responsible, then the problem would have to be rectified before valid firing tests could be conducted.

Secondary objectives of the static firing program were to measure the effect of the plume on the response of a missile to an RF field and to obtain data which could be used to determine whether an artificial plume, constructed by the Georgia Institute of Technology, adequately simulated a real plume. To measure plume effects, it was necessary to either identify and eliminate the cause of the permanent shift in interference level at motor ignition or to be able to separate a transient change in level, caused by the plume, from the permanent shift. On previous static firing tests the permanent shift masked any transient effect to the extent that such a separation was not possible.

The EMRE test site was instrumented and calibrated as specified in the original test plan. However, after it was observed that the configuration of the squib wires significantly affected the magnitude of the interference signal level during the chamber tests, the planned EMRE site test series was modified to add a sequence of tests to investigate the possibility that the interference level shift on previous EMRE tests was caused by the squib wires. The added tests were performed first and it was verified that the squib wires were the cause of the level shift. It was therefore not necessary to carry out the test series originally planned to determine which missile unit or subsystem was responsible for the level shift phenomenon.

A. TEST SERIES

The test site instrumentation system was the same as that shown in *Figure A-1* of the Appendix except that the missile configuration was identical to the configuration used for the two previous EMRE site test programs. Power was supplied to the missile by a battery pack enclosed in a cylindrical container which fit around the missile. An RF telemetry transmitter was installed in the warhead section of the missile to transmit missile data to the telemetry ground station.

A list of the tests performed at the EMRE site is shown in *Table 1*. In each of these tests the missile was mounted on the strap-down fixture on top of the fiberglass pole as shown in *Figure 3* and illuminated by an RF field at the same frequency, and with the same modulation, used previously at the EMRE site. The missile response tests consisted of measuring the interference signal level produced in the missile as the RF field strength at the missile was increased in incremental steps from Eo to 12 dB above Eo, where Eo was the field strength required

TABLE 1. TESTS CONDUCTED AT THE EMRE SITE

TEST NUMBER	MOTOR NUMBER	ASPECT ANGLE (DEGREES)	SQUIB WIRES	TYPE OF TEST
A	661403141	30	Extended	Missile Response
B	661403141	30	Tucked In	Missile Response
C	661403141	30	Cut Off	Missile Response
D	661403141	30	Cut Off	Fire
E	661302752	30	Extended	Missile Response
F	661302752	30	Extended	Fire
G	661403204	30	Cut Off	Missile Response
H	661403204	30	Cut Off	Fire
I	661302784	30	Extended	Missile Response
J	661302784	30	Extended	Fire
K	661403030	90	Cut Off	Missile Response
L	661403030	90	Cut Off	Fire
M	Aborted			
N		30	Cut Off	Artificial Plume
O		135	Cut Off	Artificial Plume
P	661403023	135	Cut Off	Missile Response
Q	661403023	135	Cut Off	Fire

to produce an interference signal approximately 3 dB above system noise. The same set of field strengths was used for all of the system response tests. These tests produced data on the difference in interference signal levels between missiles with squib wires extending out the rear and missiles with squib wires tucked in or cut off.

Firing tests were conducted by exposing the missile to an RF field large enough to produce an interference signal several decibels above system noise but 6 dB or more below saturation and continuously recording the interference signal from before motor ignition until after motor burnout. Data records from these tests show the effect of squib wires on the interference signal and the transient effect of the plume.

The artificial plume constructed by Georgia Tech was attached to an expended motor. Artificial plume tests were conducted by attaching this motor to the missile, mounting the missile on the strap-down fixture atop the fiberglass pole, and performing missile response tests. The artificial plume was 10 feet long and a special fixture and harness constructed of plywood and nylon ropes was required to support the missile and plume in the strap-down fixture. The stability of the missile and attached plume became precarious at near-vertical geometries. For this reason tests were conducted at 30 degree and 135 degree angles of incidence as planned, but the test at 90 degree angle of incidence had to be cancelled. These tests provided data for evaluation by Georgia Tech of the adequacy of the artificial plume in simulating a real plume.

B. SQUIB WIRE EFFECTS

(1) MISSILE RESPONSE TESTS. Data from the missile response tests is tabulated in *Table 2* and presented graphically in *Figure 9*. Tests A, E, and I were performed with the squib wires extending out the rear of the missile. The squib wires were tucked back into the missile skirt on test B and the wires were cut off back inside the missile skirt on tests C and G. All six of the tests were conducted with the missile at a 30 degree aspect angle with respect to the incident field. Except for the configuration of the squib wires on tests B, C, and G, the test conditions were the same as those on the two previous test programs at the EMRE site. *Figure 9* shows that there was a marked increase in missile sensitivity when the squib wires did not extend out of the missile. This result supports the hypothesis that the increase in interference level that took place at the instant of motor ignition on previous strap-down testing programs was due to the blowing away of the squib wires when the motor squibs fired.

(2) MOTOR FIRING TESTS. Fire tests F and J were conducted with the squib wires extending out the rear of the missile. On tests D and H the squib wires were cut

TABLE 2. MISSILE RESPONSE TEST DATA

TEST NUMBER	FIELD STRENGTH IN dB RELATIVE TO Eo							
	0	3	6	7.6	9	10.6	12	
A	225	227	246	270	305	372	450	
B	223	235	272	320	380	485	605	
C	222	230	270	313	375	480	595	Interference Signal Level (mV rms)
E	242	245	255	272	292	332	395	
G	253	263	292	340	395	496	610	
I	230	240	270	300	333	385	440	

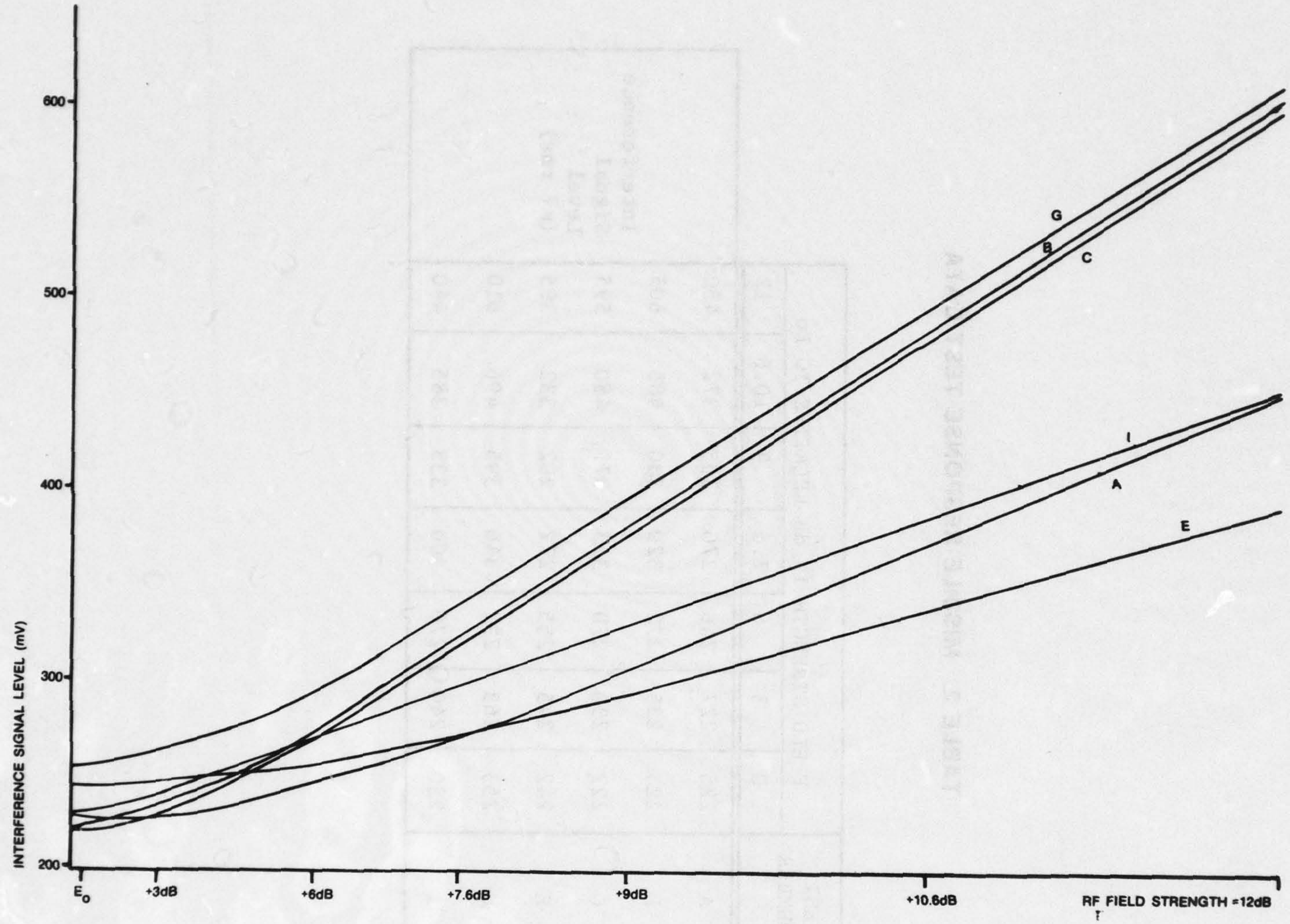

Figure 9. Missile response test data.

off back in the skirt of the missile. The test conditions on all four tests were the same as the conditions on the two previous strapdown test programs at the EMRE site except for cut-off squib wires on tests D and H. *Figures 10* and *11* are graphs of the interference signal levels measured on tests F and J by recording the output of the real-time analyzer on an XY plotter. On both of these tests, the signal level increased abruptly at the instant the motor squibs fired and remained at a higher level throughout the rest of the test period. Some evidence can be seen on both records of a small transient effect during the first few seconds of motor burn. this could possibly be a plume effect but could alternatively be due to drift in the RF field strength or missile sensitivity. Motor burn lasts for approximately 7 sec for this missile. Near the end of test F, the RF field was turned off for a few seconds and then turned back on at the same level. As seen in *Figure 10*, the interference signal returned to the same postfire level. In producing the records from the real-time analyzer, ensemble averaging was used to reduce the random system noise on the record. The difference in the magnitude of the noise seen on the different records presented in this report is the result of using different numbers of samples for the averaging.

Figures 12 and *13* are records of the interference signal levels measured on tests D and H. On both of these tests the squib wires were cut off back in the skirt of the missile. On neither test was a change in signal level seen at the instant of motor ignition. There may have been a small transient effect due to the missile plume on these tests, but such an effect cannot be definitely identified because of fluctuations in the RF field level. If the plume did affect the missile response, the change was less than 1 dB.

The results of tests A through J confirm that the abrupt change in interference signal level that occurred at motor ignition on each firing test conducted during the two previous EMRE site test programs was caused by the squib wires. Squib wires extending out the rear of a missile affect the RF sensitivity of the missile and when the squib wires are blown away, the missile response changes. Squib wires on a missile being tested for RF sensitivity should be cut off inside the missile skirt for the test to be valid.

C. PLUME EFFECTS

The data from firing tests D, F, H, and J, which were conducted with an aspect angle of 30 degrees, show that the plume had little if any effect on missile sensitivity at this aspect angle and at the RF frequency and modulation used for the EMRE site tests. Tests K and L were conducted to investigate the plume effect at an aspect angle of 90 degrees, and tests P and Q were conducted to investigate the effect at 135 degrees. Test K was conducted just prior to test L and was

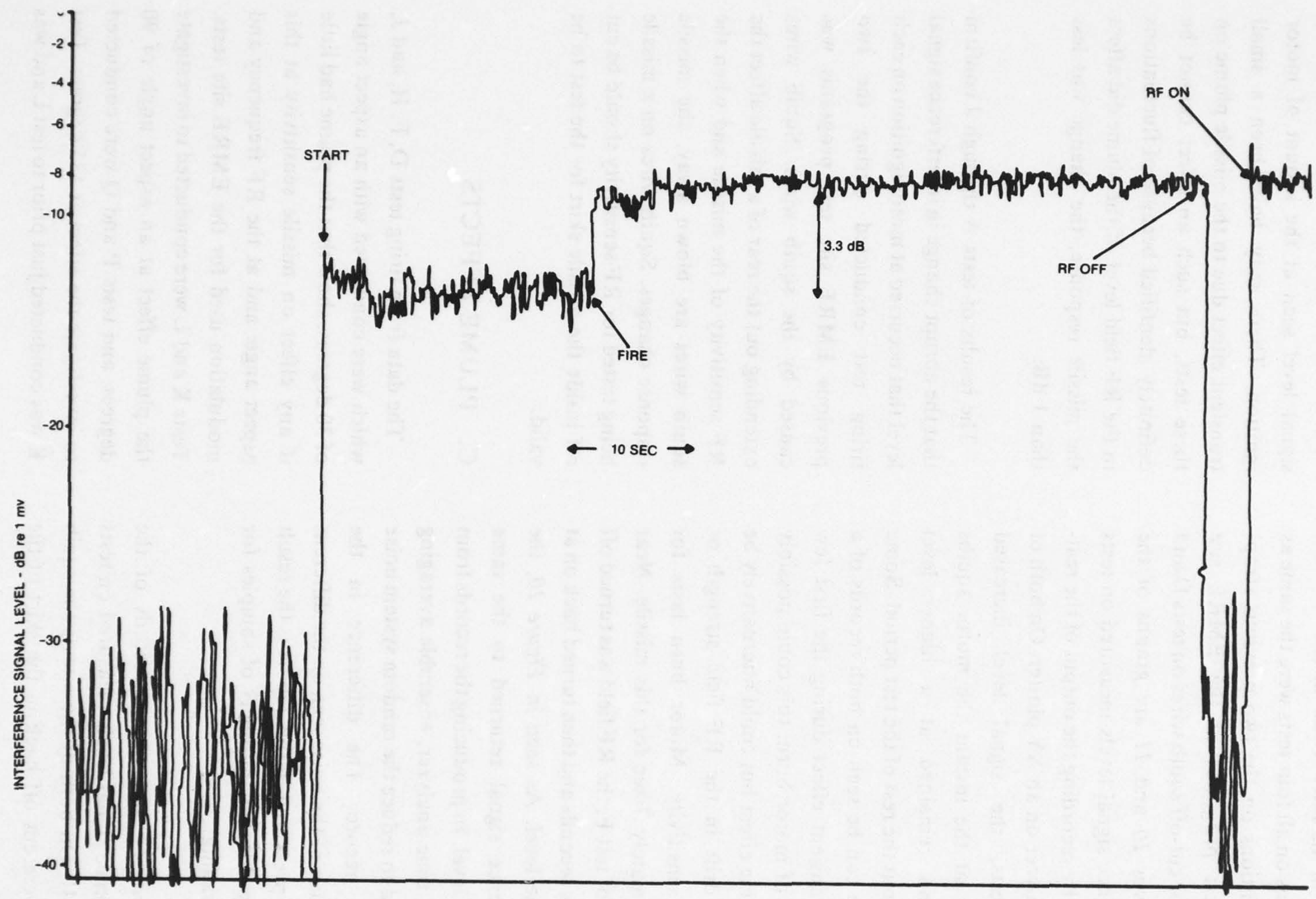

Figure 10. Data record from test F.

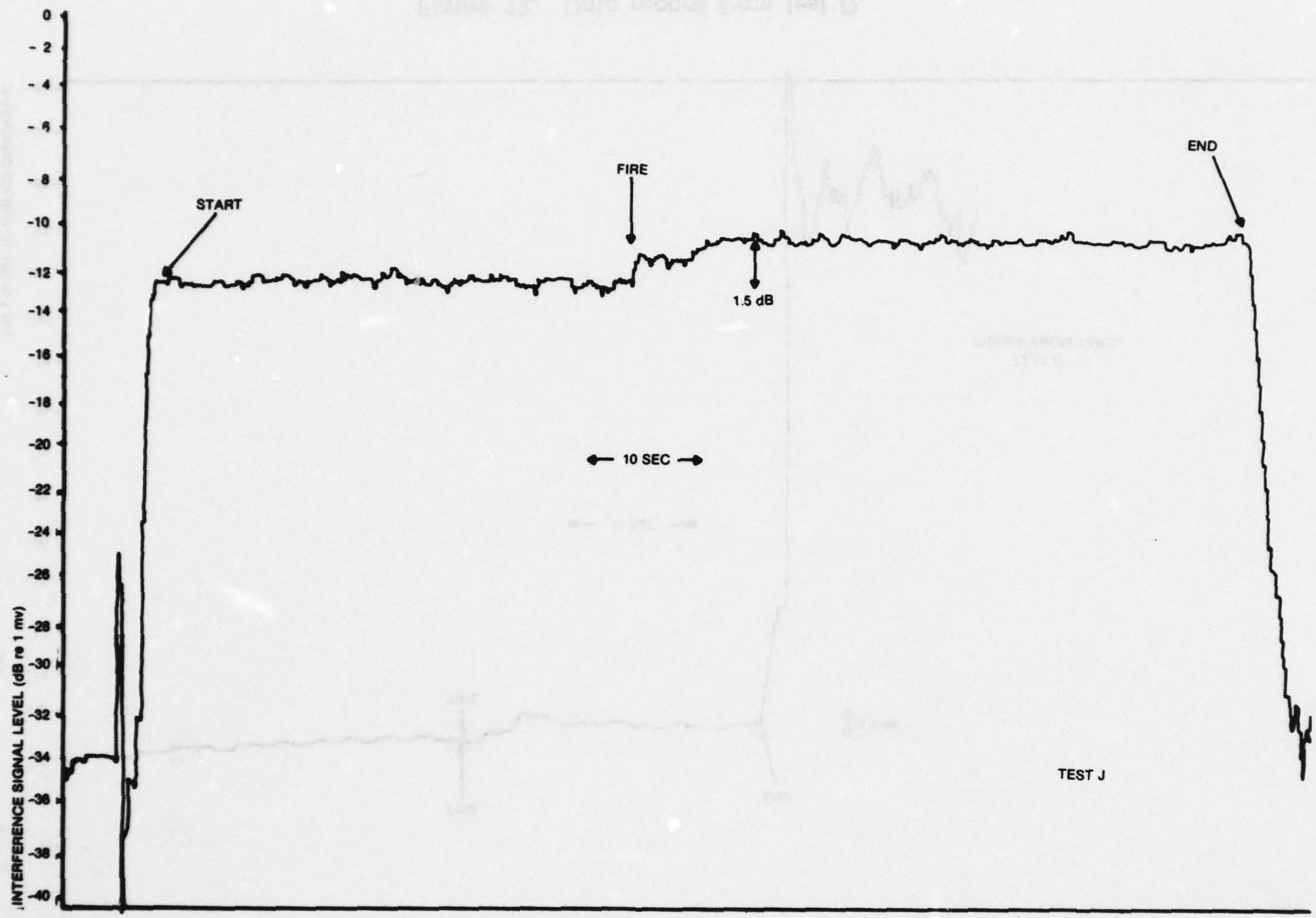

Figure 11. Data record from test J.

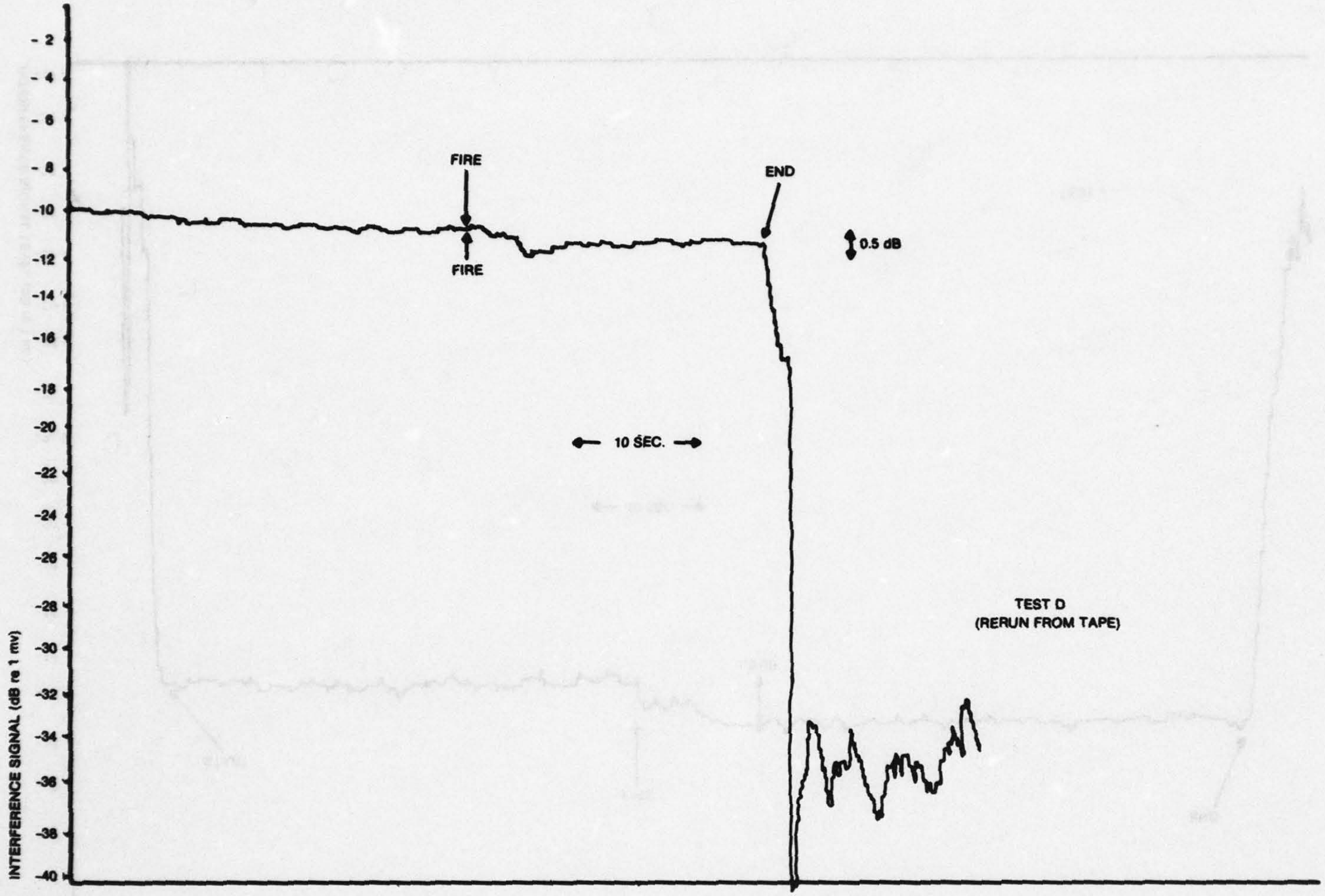

Figure 12. Data record from test D.

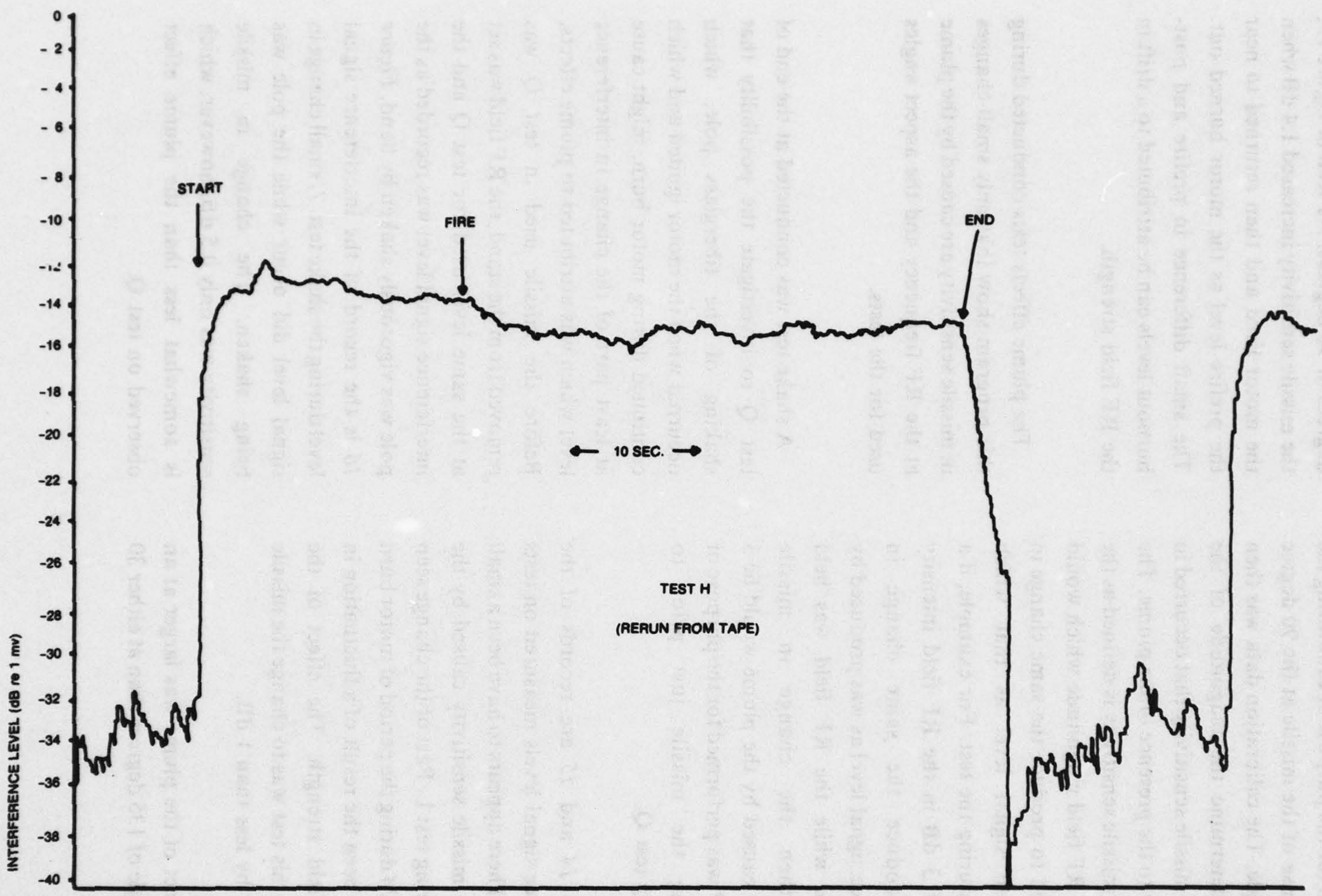

Figure 13. Data record from test H.

performed for the purpose of calibrating the RF response of the missile at the 90 degree aspect angle. The calibration data was then used to determine the magnitude of the change in missile sensitivity that occurred in test L due to the presence of the plume. The change in missile sensitivity is defined as the change in RF field magnitude which would be required to produce the same change in interference signal level as that which occurred during the test. For example, if a change of 3 dB in the RF field intensity would produce the same change in interference signal level as was produced by the plume while the RF field was held constant,then the change in missile sensitivity caused by the plume would be 3 dB. Test P was performed for the purpose of calibrating the missile just prior to conducting test Q.

Figures 14 and *15* are records of the interference signal levels measured on tests L and Q. There appears to have been a small change in missile sensitivity caused by the plume during test L. Part of the change seen in *Figure 14* during the period of motor burn may have been the result of a fluctuation in the RF field strength. The effect of the plume on this test was to change the missile sensitivity by less than 1 dB.

The effect of the plume was larger at an aspect angle of 135 degrees than at either 30 degrees or 90 degrees. As seen in *Figure 15*, the missile sensitivity increased 1.4 dB when the motor fired and then returned to near the prefire level as the motor burned out. The small difference in prefire and post-burnout levels can be attributed to a drift in the RF field strength.

The plume effects tests conducted during this program show that only small changes in missile sensitivity are caused by the plume at the RF frequency and the aspect angles used for the tests.

A shake test was conducted at the end of test Q to investigate the possibility that shaking of the fiberglass pole, which occurred when the motor ignited and which continued during motor burn, might cause at least part of the change in interference level which was attributed to plume effects. Before the missile used in test Q was removed from the stand, the RF field was set at the same level used for test Q and the interference signal level was recorded as the pole was vigorously shaken by hand. *Figure 16* is the record of the interference signal level during the shake test. A small change in signal level did occur while the pole was being shaken. The change in missile sensitivity was only 0.5 dB, however, which is somewhat less than the plume effect observed on test Q.

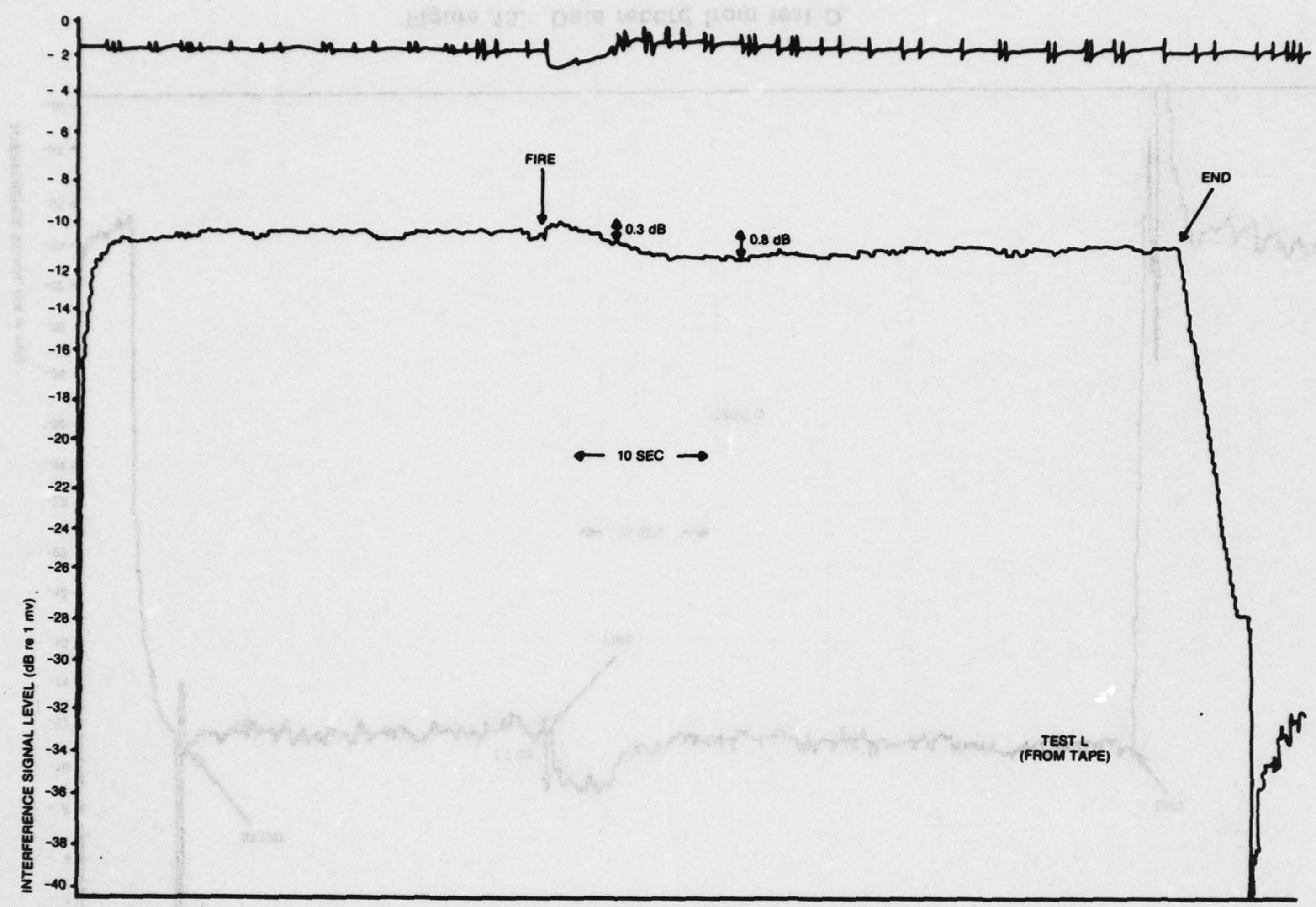

Figure 14. Data record from test L.

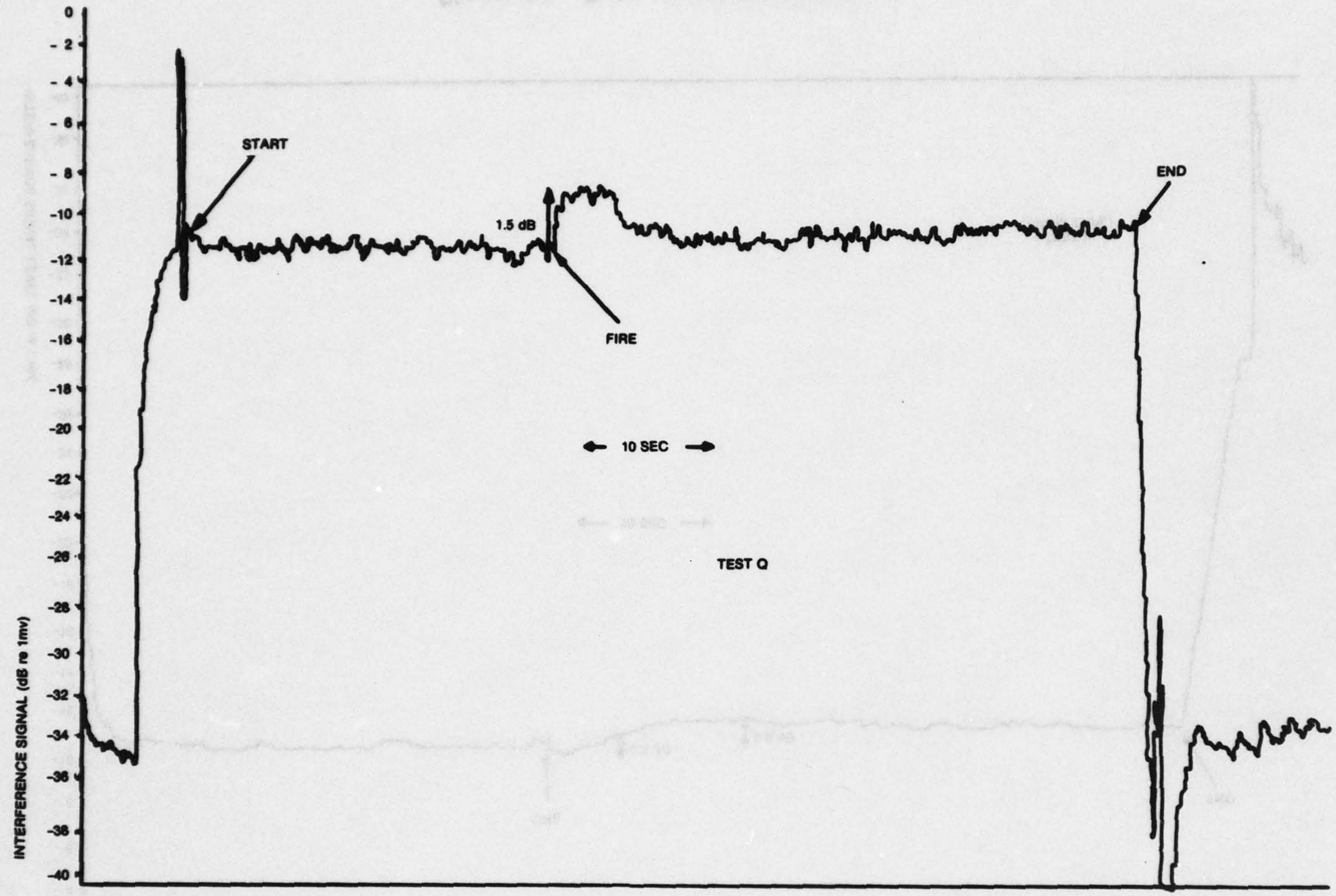

Figure 15. Data record from test Q.

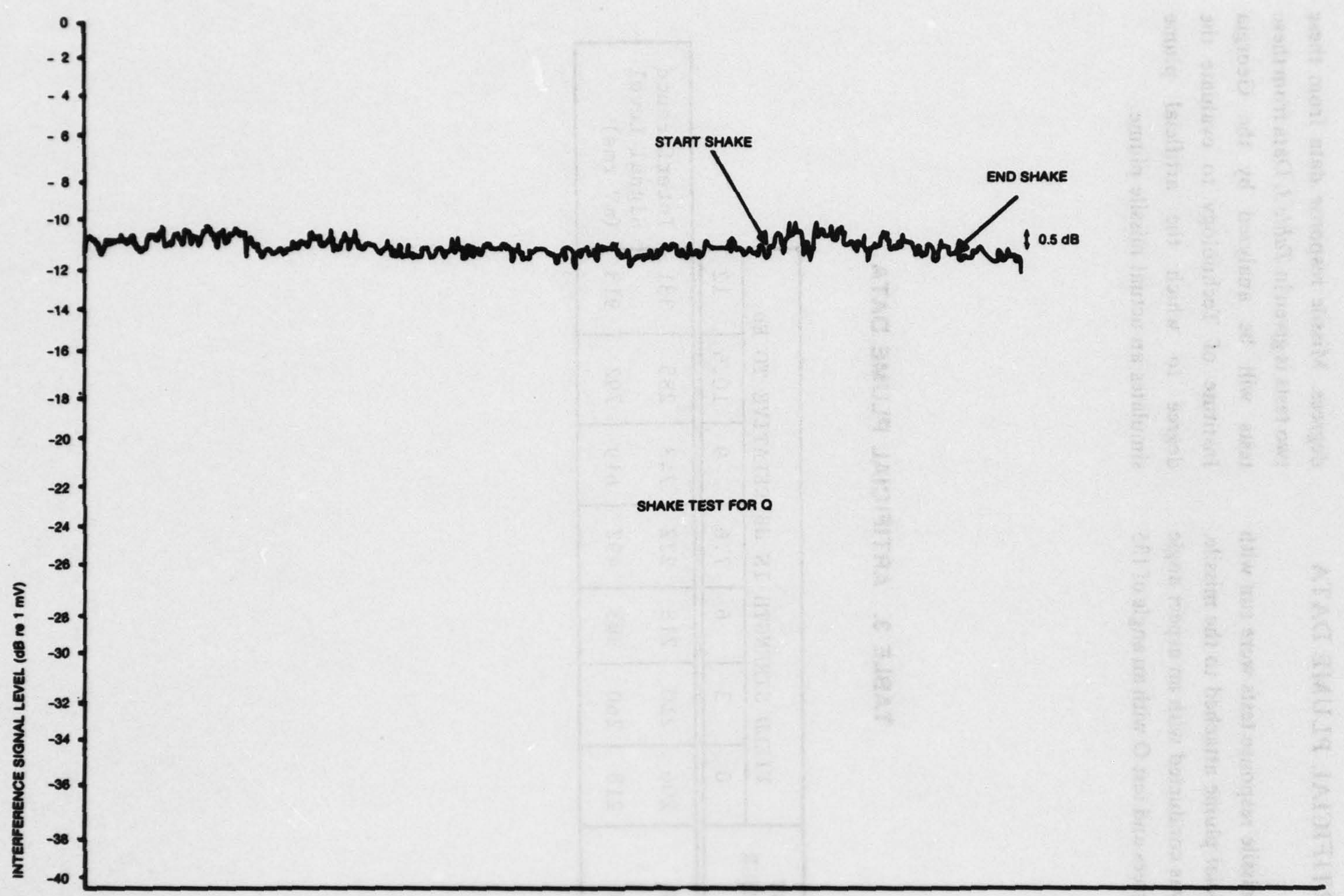

Figure 16. Data record from shake test.

D. ARTIFICIAL PLUME DATA

Two missile response tests were run with the artificial plume attached to the missile. Test N was conducted with an aspect angle of 30 degrees and test O with an angle of 135 degrees. Missile response data from these two tests is given in *Table 3*. Data from these tests will be analyzed by the Georgia Institute of Technology to evaluate the degree to which the artificial plume simulates an actual missile plume.

TABLE 3. ARTIFICIAL PLUME DATA

TEST NUMBER	FIELD STRENGTH IN dB RELATIVE TO Eo							
	0	3	6	7.6	9	10.6	12	
N	206	210	218	222	248	285	331	Interference Signal Level (mV rms)
O	218	260	383	492	619	792	913	

REFERENCES

1. Norgard, John D., and Smith, Glenn S., *A Plasma Model of Missile Exhaust Plumes*, Rome Air Development Center Report RADC-TR-77-144, April 1977.

2. Norgard, John D., and Smith, Glenn S., *Plume Effects on Rocket Susceptibility*, Rome Air Development Center Interim Report, Contract No. E-21-655, August 1977.

3. *Plume Effects Program Management Plan*, Internal document, Office of Missile Electronic Warfare, December 1977.

4. *Static Firing Program Plan*, Internal document, US Army Missile Research and Development Command, January 1978 (attached as appendix to this report).

APPENDIX

1.0 BACKGROUND

A Plume Effects Test Program was conducted in May 1977 to evaluate the effect of the missile plume on the coupling of electromagnetic energy into the interior of the REDEYE missile. Theoretical analysis of the electrical properties of the REDEYE missile exhaust plume attributes a maximum conductivity to the plume of a few tenths of an mho/m in a region close to the motor nozzle. The conductivity decreases along the length of the plume and exhibits a radial dependence. When a missile is exposed to an RF field, the presence of the plume can be expected to affect the distribution of the current on the missile skin and to thus affect the RF energy coupled into the interior through apertures such as the seeker dome. The objective of the Plume Effects Test Program was to determine whether the plume effect is significant in terms of the coupled energy and, if so, to evaluate the extent to which an artificial plume, constructed by the Georgia Institute of Technology, simulates a real plume.

The May 1977 Plume Effects Test Program was not carried out as originally planned. On the first static firing of a REDEYE missile at the EMRE test site, the captive missile was exposed to an RF field and the magnitude of the interference signal at the output of the acquisition amplifier was monitored before and after sustainer motor firing. It was observed that the interference signal changed level at the time of motor ignition and did not return to the original level after motor burnout. This was an unexpected result and the remainder of the testing period was spent devising and conducting tests to investigate this phenomenon. The level change was observed on all subsequent firing tests.

The mechanism responsible for the interference level change was not discovered during the May 1977 Plume Effects Test Program. Subsequently, laboratory tests have been conducted at the Dahlgren Naval Surface Weapons Laboratory and a second static firing test series was conducted in September 1977 at the EMRE site. These investigations have not disclosed the cause of the effect.

A Field Firing test series is planned for the REDEYE missile in the second quarter of 1978. Prior to conducting these tests it is important that a determination be made as to whether the change in the interference

signal level is due to an on-board telemetry effect, an effect associated with the strap-on battery pack that was used for missile and telemetry power, a change in the electromagnetic response characteristics of the motor, or a change in the guidance and control (GCU) section. If the telemetry is responsible, the fault must be corrected before the field firing tests take place. If the effect is due to a change in either the motor or the GCU, it must be determined whether missiles used in anechoic chamber tests represent prefired or fired missiles.

2.0 PROGRAM OBJECTIVES

The change observed in interference level during previous static firing tests has created uncertainties that must be resolved before the Field Firing tests can be carried out. First, it must be determined whether or not the effect is associated with the on-board telemetry system. If so, the problem must be corrected before field firings can be conducted. If the effect is the result of either a temporary or permanent change in the GCU or motor, then it must be determined whether or not the missiles used by Dahlgren for anechoic chamber tests adequately represent inflight missiles. Planning for the Field Firing Test Program is based on the Dahlgren chamber measurements.

The primary objectives in conducting the Static Firing Program are concerned with resolving the uncertainties that impact the Field Firing Program. Secondary objectives are concerned with determining the actual plume effect, discovering the details of the mechanism responsible for the interference level shift, and checking out the operation of the onboard RF telemetry system when it is powered by a thermal battery. The latter two of these secondary objectives need not necessarily be achieved by tests conducted at the EMRE site. After the primary objectives (listed in section 2.1) are achieved, details of the level shift mechanism can be investigated in the laboratory. Checkout of the telemetry system can be done at facilities other than the EMRE site. Tests to achieve the secondary objectives will be carried out if time and resources permit. The primary and secondary program objectives are listed in sections 2.1 and 2.2.

2.1 PRIMARY OBJECTIVES

- Determine which unit of the missile system is responsible for the interference level shift: motor, GCU, battery pack, or telemetry.

- Determine whether or not the missiles used in Dahlgren chamber tests adequately represent in-flight missiles.

2.2 SECONDARY OBJECTIVES

- Measure the plume effect and evaluate the artificial plume.

- Determine the details of the level shift mechanism.

- Check out the operation of the on-board RF telemetry system when it is powered by the missile thermal battery.

3.0 LABORATORY TESTS

Laboratory tests will be conducted at the OMEW RF test facility at WSMR. The purpose in conducting these tests is to acquire a data base for each of the guidance and control units (GCU) which will be used at the EMRE site. The data base will consist of:

- Missile Response Pattern
- Test Repeatability
- Effect of Changing Motors (motor to motor variation)
- Effect of Using the Umbilical Cable to Furnish Missile Power
- Frequency Sensitivity (effect of small change in RF frequency)
- Fin Effect (effect of change in motor configuration)

3.1 TEST EQUIPMENT

The following test items are required:

- GCU No. 1 – GCU used for EMRE site tests in September 1977.
- GCU No. 2 – New GCU acquired by OMEW.
- Expended Motors – Motors fired during previous tests at the EMRE site. (At least three required).
- Inert Motor – Furnished by MIRADCOM.
- Thermal Batteries – Four or five may be needed.

3.2 TEST INSTRUMENTATION

Telemetry System - Fiber optics system developed by OMEW. (This same system will be used at the EMRE site.)

Command System - System developed by OMEW for turning on missile and telemetry power, ejecting umbilical, and firing motor.

Tape Recorder - FM channels for data recording, one direct-record channel (2 MHz) for the serial data train, and a voice annotate capability.

Strip Chart Recorder - Four analogue and four event channels.

X-Y Plotter - with X axis (time) drive.

True RMS Voltmeter - Required for processing the acquisition amplifier data before recording on the XY plotter and the strip chart recorder.

3.3 TEST PARAMETERS

RF Frequency - Same as used in previous tests at EMRE site.

Modulation - Square wave (off-on) modulation, 50% duty cycle, same PRF as used in previous tests at the EMRE site.

Field Strength - Adjust such that the RF interference signal is easily discernible but not large enough to cause AGC action.

3.4 TEST PROCEDURES

In all tests, the motor is to be installed on the missile using a REDEYE torque spanner. Unless otherwise indicated, tests are to be performed with missile power supplied through the umbilical in exactly the same manner and configuration which will be used at the EMRE site. Calibrate the field at the missile pedestal (before the missile is installed) with equipment which can also be used at the EMRE site. Check the field calibration as often as necessary to be certain of the field strength at all times.

3.5 DATA RECORDING

For data acquisition, the same fiber optics telemetry system will be used in the laboratory and at the EMRE site. Data to be recorded on magnetic tape will be:

- Acquisition Signal
- Sigma Dot
- Thermal Battery Voltage
- Missile Power
- Event Markers (missile power on, TM on, thermal battery on, umbilical eject)
- Serial Data Train (2 MHz direct-record channel)
- Data annotate (by voice) - date, time, test number, test title, objective, events (power on, TM on, etc.), and other information that may be pertinent to data interpretation or for later comparison with EMRE site data.

Data to be recorded on the strip chart will be a through e in the above list.

The acquisition signal amplitude will be measured by a true RMS voltmeter and the output of the voltmeter will be recorded on the Y axis of an XY plotter. The X axis of the plotter will record aspect angle, frequency, or time as appropriate for the particular test being conducted.

3.6 TEST PLAN

The following laboratory tests are to be performed:

a. Missile Response Pattern with Expended Motor, GCU No. 1 - Measure

pattern of GCU No. 1 with expended motor attached.

b. Missile Response Pattern with Inert Motor - Repeat test No. 1 with inert motor.

c. Test Repeatability - Repeatability tests are conducted by placing the missile on the stand and determining the field strength required to produce a certain level of interference on the acquisition signal. Then turn off missile, telemetry, and transmitter power, remove missile from stand, place missile back on stand, and again measure the field strength required to produce the same interference level on the acquisition signal. Repeat this process three times. Next, go through the same process three times, but remove and reinstall the motor when the missile is removed from the pedestal. Perform the repeatability tests with the GCU and motor used in test No. 1. Place missile at an aspect angle which is on the side of a main response lobe (where the response is varying rapidly with aspect angle).

d. Frequency Sensitivity - With same GCU, motor, and aspect angle used in test No. 3, measure the missile response (interference level on the acquisition signal) as the transmitter frequency is varied from f - 10 MHz to f + 10 MHz where f is the frequency used for the EMRE site tests.

e. Fin Effect - With same GCU, motor, and aspect angle used in test No. 3, measure change in response when two missile fins are removed. Repeat with all four fins removed.

f. Motor to Motor Variation - With same GCU and aspect angle used in test No. 3, measure the missile response (field strength required to produce a fixed level of interference on the acquisition signal) with at least three (five, if possible) different expended motors and with the inert motor. Repeat with the aspect angle used for EMRE site tests in September 1977.

g. Search for Motor Changes - Visually inspect and compare a live motor with an expended motor. Pay particular attention to nozzle and fin assemblies. Measure diameters and lengths of both. Make impedance measurements where appropriate.

h. Missile Response Pattern with Expended Motor, GCU No. 2 - Repeat test No. 1 with GCU No. 2. Use same expended motor.

i. Effect of Umbilical Cable - If thermal batteries can be fired in chamber, conduct test in the same sequence that will be used at the EMRE site. Use GCU and motor used in test No. 1. Use same aspect angle used at EMRE site in September 1977.

4.0 EMRE SITE TESTS

4.1 TEST EQUIPMENT

The following test items are required:

- GCU No. 1 - GCU used for EMRE site tests in September 1977.

- GCU No. 2 - New GCU acquired by OMEW for which pattern measurements have been made in the OMEW chamber.

- Expended Motors - Motors fired during previous tests at the EMRE site which were used in the OMEW laboratory motor to motor variation tests. At least three (preferably 5) required.

- Live Motors - 15.

- Thermal Batteries - 20.

4.2 TEST INSTRUMENTATION

ITEM		DESCRIPTION
Transmitter	1.	**Transmitter and antenna used in previous static firing tests at the EMRE site. Antenna to be mounted on same fixture and at same location as used on previous tests.**
Telemetry	1.	Fiber Optics - Same fiber optics TM system used in OMEW laboratory tests. Receiver located in instrumentation van.
	2.	RF - Same RF telemetry transmitter used for previous EMRE site tests. Power to be furnished either through umbilical or from battery pack used in previous tests. Receiver located in instrumentation van.
Command System	1.	OMEW System - System developed by OMEW and used in laboratory tests, to turn on telemetry and missile power, eject umbilical, and fire motor.
	2.	Dahlgren System - Touch-tone system developed by Dahlgren and used in previous EMRE tests.
Recording Equipment	1.	Tape Recorder - Eight FM analogue channels, one 2 MHz direct-record channel for recording the serial data train. Provisions for voice annotate and time code. Record/reproduce modules for each channel. Eight rolls of tape.
	2.	Strip Chart Recorder - Four analogue and four event channels.
	3.	XY Plotter with Time Base Drive.
	4.	Oscilloscope Camera.
	5.	Still Camera.

Power Supply	**1.**	**DC Power Source - For powering missile through the umbilical.**
Test and Monitoring Equipment	**1.**	**True RMS Volt Meter.**
	2.	**Real-Time Spectrum Analyzer.**
	3.	**Oscilloscope - Instrumentation van, 50 MHz.**
	4.	**Oscilloscope - Transmitter room, 500 MHz.**
	5.	**Power meter with Spare Thermistor.**
	6.	**Counter - 500 MHz, capability to read on a 50 percent duty factor signal.**
	7.	**B Dot Probe, Coupler, and Detector - supplied by MIRADCOM.**
	8.	**E Field Probe and Meter - Same system used by OMEW in the big chamber.**
	9.	**IRIG Time Code Receiver.**
	10.	**Function Generator.**
Miscellaneous	**1.**	**Power Supplies - As required to charge OMEW telemetry batteries and batteries in Dahlgren battery pack.**
	2.	**Volt Ohm Meter, Test Leads, Soldering Equipment Tools, etc.**
	3.	**Communication System - Hard wire system, connecting all test stations.**
	4.	**REDEYE Torque Spanner for Installing Motors.**

4.3 SITE PREPARATION AND CALIBRATION

4.3.1 SITE PREPARATION. Site preparation involves setting up and adjusting the instrumentation necessary for conducting the tests. Checks will also be made to determine that all of the desired data can be recorded with the test equipment on hand. This task must be completed before commencing with any tests and will be carried out in ample time to rectify any instrumentation or equipment problems.

a. Transmitter Modulation. During the site preparation, the transmitter to be used to illuminate the missile will be checked to insure that it can provide the desired signal. Those parameters to be checked are:

- The desired transmit power
- The desired percentage of modulation (100 percent)
- The desired pulse repetition frequency
- The desired duty cycle (50 percent)

b. Field Monitoring System. The field monitoring system will be installed and checked to insure that it is functioning properly. This involves mounting the B probe, running the feedline for the probe to the transmitting shack, installing the detector and calibrating the scope used with the detector, checking the power output of the B probe on an accurate power meter, and running data lines from the detector and power meter to the tape and strip chart recorders (*Figure A-1*). This system will be used to provide a constant, instantaneous measurement of the E field at the missile.

c. Data Acquisition and Recording System. The missile data acquisition system consists of the signal-conditioning circuitry and telemetry transmitter on the missile, the fiber optics-optical detector - coaxial cable data link, and the telemetry ground station which is located in the instrumentation van. The recording system consists of a magnetic tape recorder, strip chart recorder, and XY plotter. The missile data acquisition and recording systems will be set up and each data channel checked and adjusted for proper sensitivity, dynamic range, and frequency response. The missile data to be recorded on magnetic tape, strip chart, and XY plotter are shown in *Figure A-1*.

In addition to the missile data, the RF field strength and modulation envelope will be recorded on magnetic tape and strip chart recorder. The magnetic tape will be voice annotated, and an IRIG time code will be recorded. Each of these data channels will be set up and checked out during site preparation.

d. Missile Command System. The command system developed by OMEW to turn on missile power, turn on the telemetry

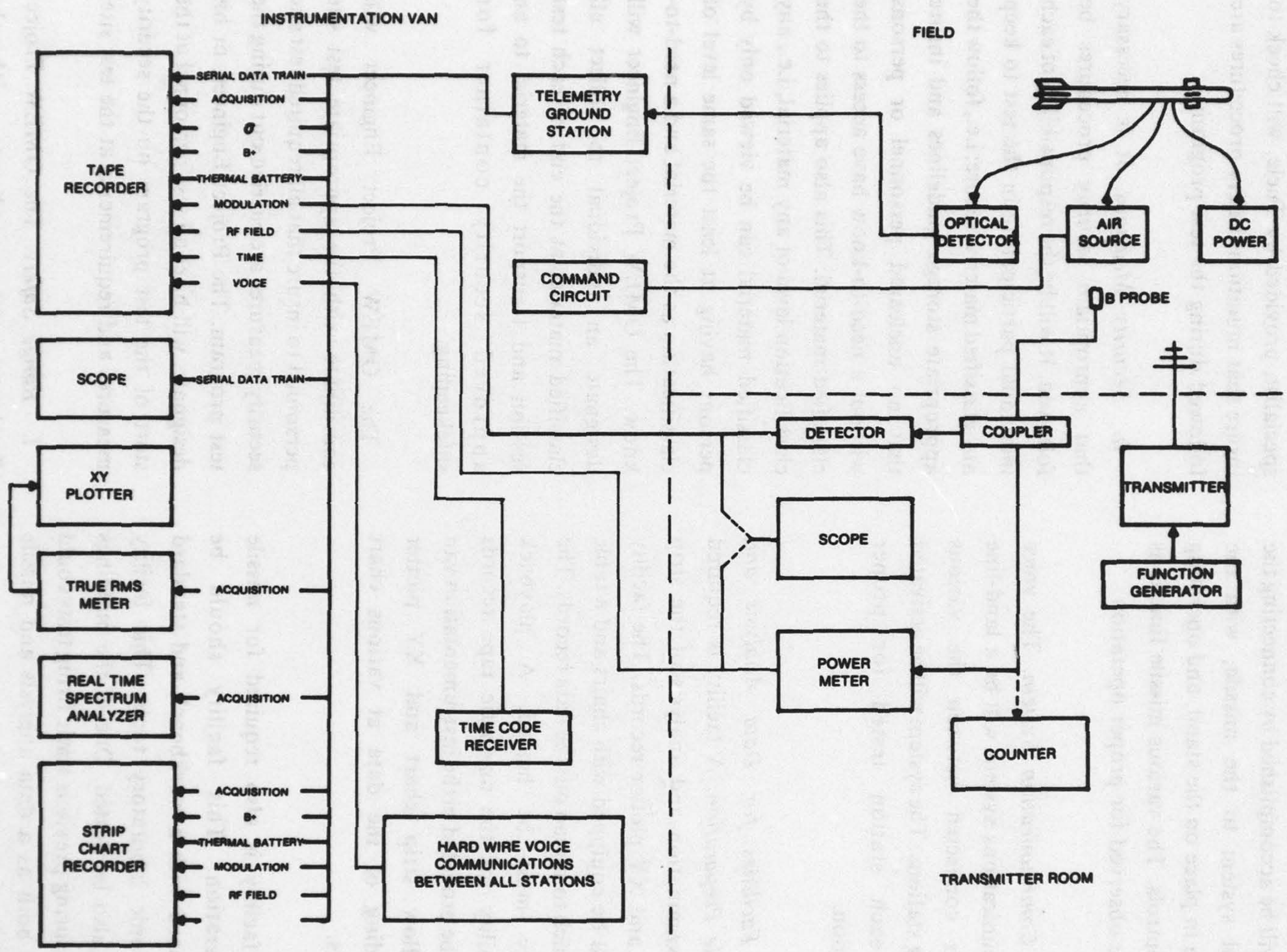

Figure A-1. Instrumentation System.

transmitter, fire the thermal battery, eject the umbilical, and fire the motor will be checked for proper operating condition. This will be accomplished by connecting the control system to the missile, with the missile in place on the stand, and operating the controls. The various missile functions will be observed for proper operation.

e. Communication System. The voice communications system will be a land-line system connected between the various testing stations. The system will be activated and each station tested for proper operation.

f. Facilities for Data Analysis and Missile Preparation. A facility is required for examination and analysis of the strip chart and XY plotter records. The facility should be equipped with chairs and a table on which to spread out the data records. The facility must be heated. A playback capability for the magnetic tape records must be provided in the instrumentation van to allow strip chart and XY plotter recording of the data at various chart speeds.

A facility is also required for missile preparation. This facility should be equipped with a workbench and standard electronic laboratory tools. This facility must also be heated. One of the buildings used during previous static firing tests could serve both as a data analysis and missile preparation facility.

g. Munitions Storage and Handling. Proper munitions storage and handling procedures will be observed. A munitions specialist, provided by Tuele, will check to insure that munitions safety procedures are followed during the test program.

h. Security Measures. It is necessary that appropriate security procedures be followed. It will be the responsibility of each individual participating in the test to keep any classified material secure; i.e., follow the appropriate storage guidelines and insure that no uncleared personnel or persons without a need-to-know have access to the classified material. This also applies to the classification level of any material, i.e., any classified material can be viewed only by persons having at least the same level of classification as the material and a need-to-know. The OMEW Project Engineer will designate an individual to collect all classified material at the end of each test session and transport the material to an approved security container for safekeeping.

The OMEW Project Engineer will coordinate with the appropriate test site personnel to insure that all required test site security measures are carried out during the test program. The Project Engineer, or his designate, will brief all test personnel at the start of the test program on the security measures and requirements at the test site.

i. Range Safety. The OMEW Project Engineer will coordinate with the

appropriate test site personnel and with the munitions specialist to establish the range safety requirements which will be in effect during this test program. The Project Engineer will brief all test personnel on the range safety requirements and will enforce range safety measures.

4.3.2 SITE CALIBRATION. A B-dot probe will be mounted between the antenna and the missile stand at a location where reflections from the probe will not perturb the field at the missile, the VSWR of the antenna will not be affected, and reflections from the missile will not affect the probe reading. The signal from the probe will be used to determine the field strength at the missile and to display and record the percentage modulation, PRF, and duty factor.

The field strength at the missile will be determined by measuring the power from the B-dot probe with a standard power meter. A calibration factor, which relates the B-dot power to the field strength at the missile, must be determined experimentally. The following procedure will be used to determine the calibration factor:

- The B-dot probe will be installed at a fixed location approximately ten feet in front of the antenna. The probe will be mounted on a PVC pole at a height of about six feet. The probe will be connected by a coaxial cable to the power meter in the transmitter room as shown by *Figure A-1*.

- The electric field probe which is used for making E field measurements in the OMEW chamber will be mounted on the missile strap-down block at the top of the missile stand.

- The RF transmitter will be adjusted to a power level of 200 watts and both the field strength at the strap-down block and the B dot power will be recorded. The field strength E and the power P are related by the equation:

$$E=k\sqrt{P}\ .$$

The calibration factor, k, can now be calculated from the measured values of E and P.

- The measurement of E and P will be repeated at RF transmitter power of 7, 27, 100, 200, 400, 800, 1000, and 2000 watts to check the probe linearity.

- With a transmitter power of 200 watts, the B-dot power will be monitored while the electric field probe is removed from the missile stand and a missile is installed. After installation of the missile, the B-dot power should be the same as before the missile was installed. If not, the probe location will be changed until the presence of the missile does not affect the probe power reading.

4.4 TEST PARAMETERS

- RF Frequency - Same frequency used in previous static firing tests.

- Modulation PRF - Same PRF used in previous static firing tests.

- Percent Modulation - 100 percent (off-on).

- Duty Factor - 50 percent.

- Aspect Angle - Will use three:

(1) Same angle used in September 1977 tests.

(2) Angle on side of front lobe (determined from OMEW missile response patterns).

(3) Angle of rear lobe.

4.5 TEST TEAM ORGANIZATION

The functions that must be performed at the EMRE test site, and the individuals who will be responsible, are shown in *Figure A-2*. Descriptions of each of these functions are given in the following paragraphs:

4.5.1 TEST DIRECTOR. The Test Director has overall responsibility for conducting the test program and achieving program objectives.

4.5.2 PROJECT ENGINEER. The Project Engineer has overall responsibility for management, administration, coordination and liaison of all efforts in the static firing program.

4.5.3 SITE COORDINATION AND ADMINISTRATION. This function includes coordination and liaison with EMRE site personnel regarding facilities, EMRE equipment, security, range safety, and other matters as required.

4.5.4 RF ENVIRONMENT CONTROL. Environment control includes setting the missile at the proper aspect angle, assuring the RF integrity of the site and missile stand, operating the transmitter, and establishing the RF frequency, field strength, modulation, and duty factor called for by the test plan or by the Test Director. On each test the required RF environment shall be established and monitored. Personnel responsible for environment control shall also be responsible for assuring that calibrated analogue signals representing the field strength and the modulation envelope are supplied to the instrumentation van for recording on magnetic tape and strip chart. The field strength signal will be a calibrated DC voltage from the power meter in the transmitter room (*Figure A-1*). The modulation envelope signal is supplied by the crystal detector in the transmitter room. An environment log shall be kept in which

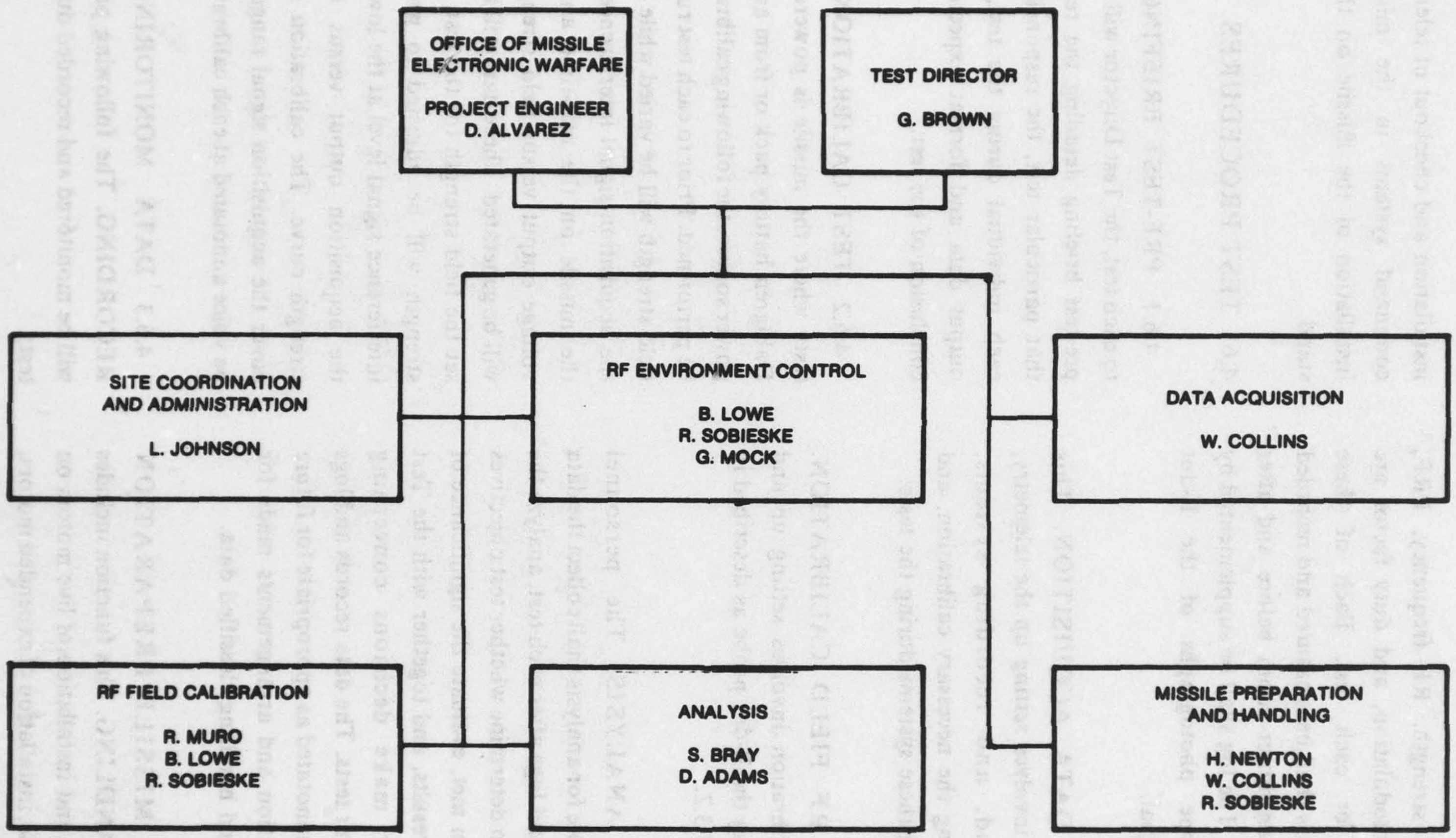

Figure A-2. Static firing test organization.

the field strength, RF frequency, PRF, percent modulation, and duty factor are entered for each test. Each of these parameters shall be measured and recorded at the transmitter room before and after each test. The log shall be supplemented by oscilloscope photographs of the B-dot probe signal.

4.5.5 DATA ACQUISITION. This function involves setting up the telemetry, command, and recording systems, performing the necessary calibration, and operating these systems during the tests.

4.5.6 RF FIELD CALIBRATION. Field calibration involves setting up and calibrating the B-dot probe as described in Section 4.3.2.

4.5.7 ANALYSIS. The personnel responsible for analysis shall collect the data records and logs after each test, analyze the records to determine whether test objectives have been met, evaluate the significance of the test results, and together with the Test Director make decisions concerning subsequent tests. The data records and logs shall be annotated as appropriate for future identification and arrangements made for storing and handling classified data.

4.5.8 MISSILE PREPARATION AND HANDLING. This function includes handling and installation of live motors on the missile, installation of expended motors, installation and checkout of telemetry and command systems in the missile, and installation of the missile on the missile stand.

4.6 TEST PROCEDURES

4.6.1 PRE-TEST BRIEFINGS. Prior to each test, the Test Director will conduct a pre-test briefing detailing the reasons for that particular test, the responsibilities of each individual during the test, and the output data and format expected at the conclusion of the test.

4.6.2 TEST CALIBRATION. On all tests where the missile is powered by the Dahlgren battery pack or from an external power source, the following calibrations will be performed. Prior to each test run, the RF field strength will be varied while observing the acquisition signal interference levels of the missile on the real-time analyzer. A voltage output versus field strength curve will be generated. These data will be used to set the field strength for the test. The field strength will be adjusted to produce an interference signal level at the lower end of the acquisition output versus RF field-strength curve. The calibration steps will cover the acquisition signal range and will be voice annotated at each calibration level.

4.6.3 DATA MONITORING AND RECORDING. The following parameters will be monitored and recorded during each test:

a. Exposure Field

• Radio-frequency Power at the Transmitter Output (RF environment log).

• Electric Field Strength at the Missile (RF environment log, tape recorder, strip chart).

• RF Frequency (RF environment log).

• Modulation PRF (RF environment log, tape recorder, strip chart).

• Percent Modulation (RF environment log, tape recorder, strip chart).

b. Missile Parameters

• ACQ (tape recorder, strip chart, XY plotter, monitored on real-time analyzer).

• SDT (tape recorder).

• σ (tape recorder).

• Missile B+ (tape recorder, strip chart).

• Thermal Battery Voltage (tape recorder, strip chart).

4.6.4 VOICE ANNOTATION. The magnetic tape will be voice annotated with all pertinent information concerning the test.

Specifically, the audio track should include the following:

1. test run number
2. time and date
3. tape footage reading
4. missile/seeker/TM serial numbers
5. RF field strength
6. RF frequency
7. modulation PRF and percent modulation
8. angle of incidence
9. polarization
10. timing (count-down, TM on/off, missile on/off, transmitter on/off, firing, etc.)

4.6.5 ON SITE DATA ANALYSIS. Strip chart records, XY plotter charts, and

test logs will be collected by the test analysts immediately after each test. The analysts will examine the records to determine if test objectives have been met, evaluate the significance of the results, and together with the Test Director make decisions concerning subsequent tests.

4.7 FIRING TEST SEQUENCES

Firing tests will be conducted with two different missile configurations. In one configuration, missile data is acquired via a fiber optics telemetry system and missile power is supplied initially through the umbilical cable and at time of firing by an on-board thermal battery. The other configuration is the one used for previous static firing tests. Missile and telemetry power is supplied by a strap-on battery pack and an RF telemetry link is used for data acquisition.

The firing test sequence for tests in which the fiber optics telemetry system is used is listed in *Table A-1* and shown diagrammatically in *Figure A-3*. The firing test sequence for the RF telemetry configuration is listed in *Table A-2* and diagrammed in *Figure A-4*.

4.8 TEST PLAN

The tests to be conducted at the EMRE site are shown in the test diagram of *Figure A-5*.

TABLE A-1. FIRING TEST — FIBER OPTICS TELEMETRY

TIME	EVENT	
T-240	Test directions	test number aspect angle RF frequency field strength polarization modulation - type, PRF, percent
T-180	TM receiver on	
T-150	Transmitter on field monitoring system on	
T-120	Transmitter room report	aspect angle RF frequency field strength polarization modulation - type, PRF, percent
T-90	Transmitter off	
T-90	Tape recorder on	
T-90	Label tape	test run number date and time tape footage reading description of test - objective GCU, motor, TM serial numbers angle of incidence polarization field strength frequency modulation - type, PRF, percent
T-30	Strip chart recorder on, XY plotter on, RTA on	
T-0	Missile TM on (Start data acquisition sequence)	
T+10	Missile power on (through umbilical)	
T+20	RF on	
T+35	RF off	
T+45	Thermal battery on	
T+47	Eject umbilical	
T+49	RF on	
T+52	Fire motor	
T+100	End test - all equipment off	
	Transmitter room report	

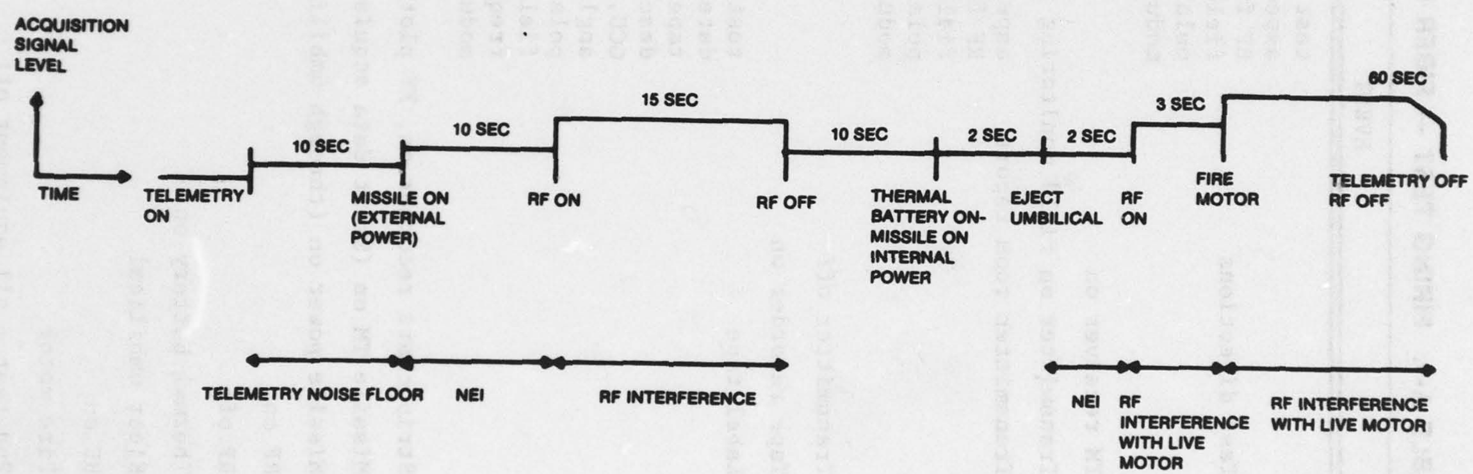

Figure A-3. Data acquisition sequence — fibre optic telemetry.

TABLE A-2. FIRING TEST — RF TELEMETRY

TIME	EVENT	
T-240	Test directions	test number aspect angle RF frequency field strength polarization modulation - type PRF, percent
T-180	TM receiver on	
T-150	Transmitter on, field monitoring system on	
T-120	Transmitter room report	aspect angle RF frequency field strength polarization modulation - type, PRF, percent
T-90	Transmitter off	
T-90	Tape recorder on	
	Label tape	test run number date and time tape footage reading description of test - objective GCU, motor, TM serial numbers angle of incidence polarization field strength frequency modulation - type, PRF, percent
T-30	Strip chart recorder on, XY plotter on, RTA on	
T-0	Missile TM on - start of data acquisition	
T+30	Missile on	
T+60	RF on	
T+90	Fire motor	
T+150	End test - all equipment off	
T+180	Transmitter room report	

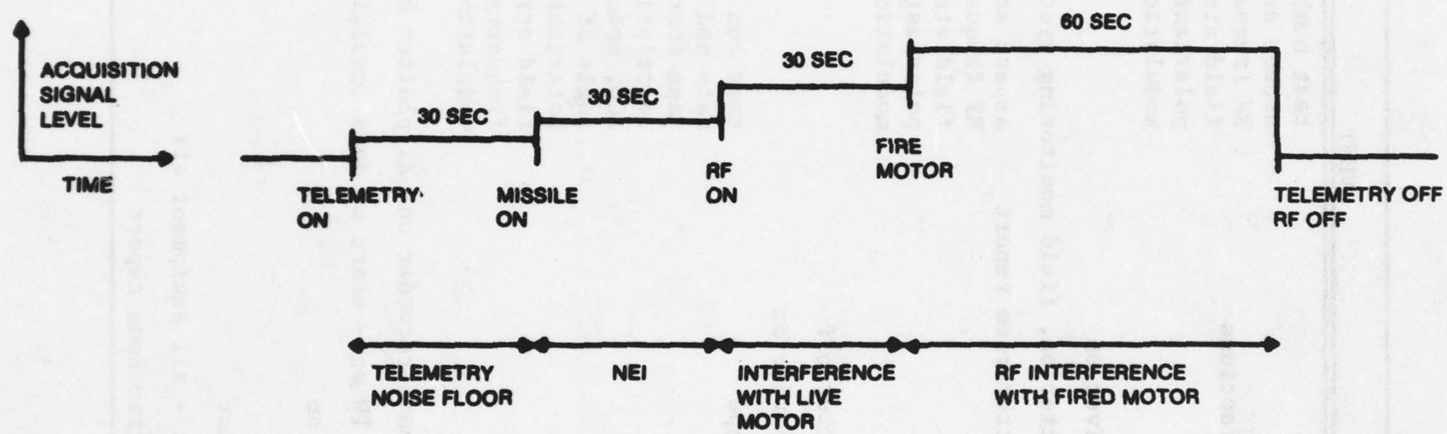

Figure A-4. Data acquisition sequence — RF telemetry.

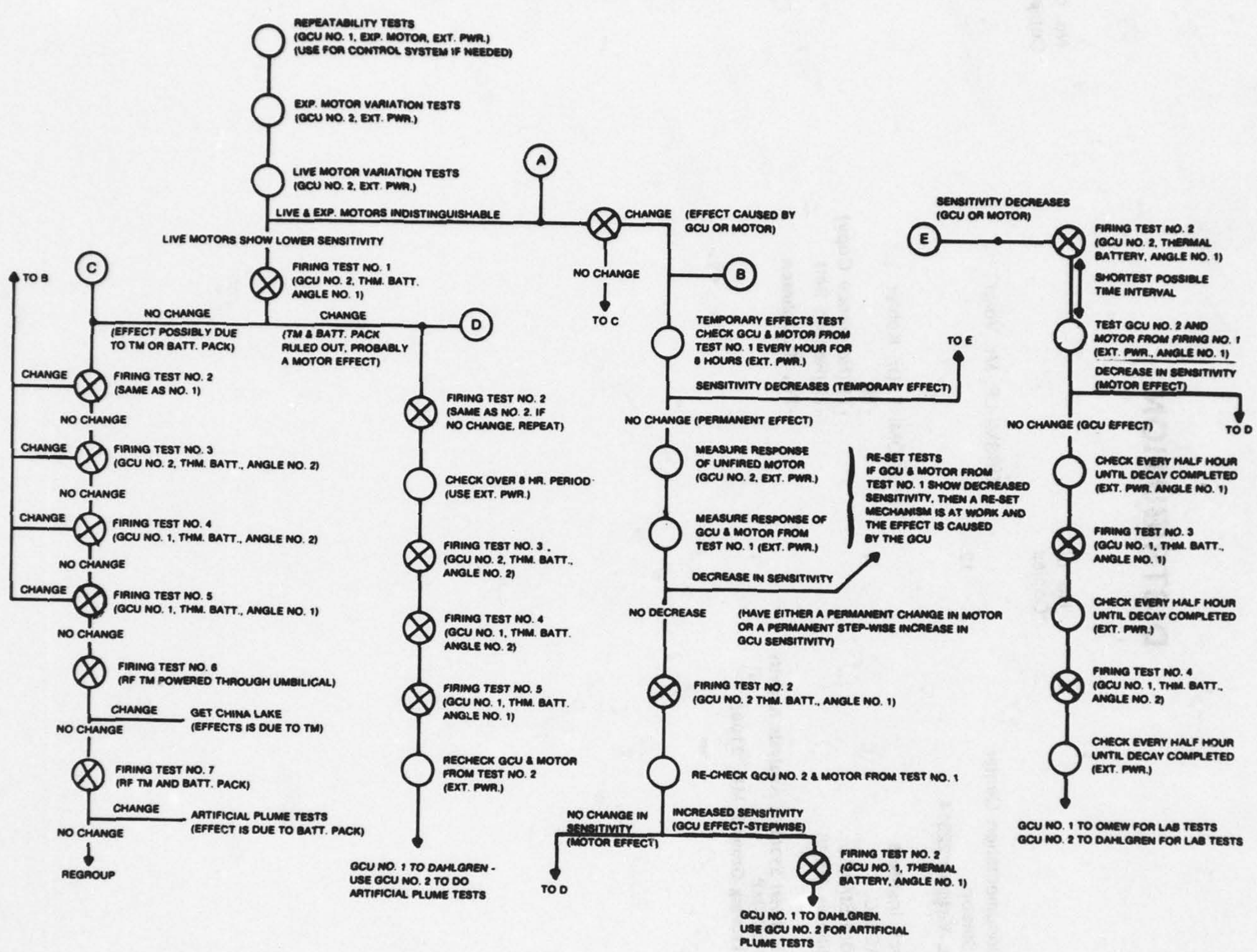

Figure A-5. EMRE site test plan.

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